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RESEARCH AND DEVELOPMENT ON CRYOGENIC STRETCH-FORM HELIUM BOTTLES FOR THE SATURN V, S-IC VEHICLE

FINAL REPORT

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NOTICE

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The performance of work under this Contract has been accomplished through the utilization of the ARDEFORM Process which is the subject of U.S. Patent No. 3197851 awarded to Arde-Portland, Inc.

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I · ABSTRACT

'he development and fabrication of high pressure helium bottles for space vehicle applications was undertaken through the utilization of "ARDEFORM" cryogenic stretch forming techniques. The configurational features of the helium bottles immersed in the LOX tanks of the Saturn V, SIC vehicle were duplicated in sub-scale pressure vessels. Two designs were initiated, and later fabricated. One design utilized standard manufacturing processes for the production of a welded vessel made from plate stock. The other design provided for an integral head, non welded bottle, fabricated from seamless tubing.

Materials evaluation, metallurgical studies, weld development, and materials testing programs were carried out in support of this work to show the feasibility of producing full scale Saturn tankage. It was shown that the fabrication technology developed could be readily utilized in the production of vessels. Welded vessels tested in the program achieved 337 KSI nominal hoop stress at cryogenic (-320°F) burst, while integral head vessels burst at 316 KSI nominal cryogenic hoop stress. Mechanical testing indicated average uniaxial yield strengths of 300 KSI and average K_{1C} (plane strain fracture toughness) values of 85 KSI $\sqrt{in}$ at -320°F. 100% weld efficiency was also demonstrated.

II INTRODUCTION

The ARDEFORM process was conceived by Arde-Portland as a means of fabricating high strength pressure vessels from AISI-301 Stainless Steel. This process utilizes the property of austenitic stainless steels to work harden to very high strength levels when stretched at cryogenic temperatures. The process consists of fabricating an undersize pressure vessel from work hardenable material while the material is still in an annealed condition. The undersize vessel is then stretched, at cryogenic temperatures, to the full size required. The cryogenic stretching operation imparts high strength to the entire vessel including end closures and all welds.

The ARDEFORM process for fabricating high strength stainless steel tankage has achieved significant acceptance for missile and space application. The unique capability of providing extremely light weight pressure vessels in conjunction with attractive material physical properties and compatibility with a wide range of fluids has made it an obvious candidate for flight hardware. Among the more notable applications which are completed or are currently under way are:

Gemini Life Raft CO_2 Inflation Bottle

This is a cylinder two inches in diameter and approximately 10 inches long designed for a burst pressure of 5600 psi for NASA Manned Spacecraft Center. These vessels have been fully qualified for manned flight and have been used on the last five Gemini flights. This has been a production type program with over 100 units having been delivered to date.

Roadrunner I - N_2 Pressurant Tank

A 100 inch long by 4 3/8" diameter N_2 pressure vessel which is immersed in the propellant tank on the NAA target missile. Burst pressure is 600 psi and the design ultimate strength is 280,000 psi. A quantity of 47 units have been delivered to NAA in addition to qualification test units used to demonstrate design requirements. These units have been flying on recoverable target drones.

Roadrunner II - N_2 Pressurant Tank

An unusual tank configuration which makes use of a toroidal head to provide a maximum volumetric efficiency vs total length. A total of 12 units of this 12" diameter, .150 wall cylinder have been delivered for use in an advanced version of the NAA Road-runner. The design ultimate stress is 300,000 psi. An interesting demonstration of the resistance of ARDEFORM material to impact damage occurred when a drone creashed early in the flight and the tank was found to be still intact.

Biosatellite N_2 Tank

A 14 1/2" diameter, .080 wall spherical pressure vessel developed for General Electric Company for this application has passed qualification tests and six vessels have been delivered. In this spherical vessel the design ultimate stress is 270,000 psi.

Agena O_2 Vessel

Several 7 1/2" diameter, 10,000 psi burst strength spheres were provided to Lockheed for a special mission. Full qualification was completed using only two vessels. The flight was accomplished in 1965.

Cryogenic O_2 Storage

A development program to produce 25" diameter .040 wall spheres for cryogenic dewar inner vessels has been completed for Bendix. These vessels were fabricated using a unique composite preform consisting of a cylinder, two cones and two flat plates eliminating the need for costly forging and forming operations. Further, the finished weight is one-half that of an identical configuration vessel made from inconel, in use on the Apollo program.

Cryogenic H_2 Storage

A parallel program for Bendix to the one above is a development of composite sphere for a 28" diameter vessel with .020" wall thickness. This project approaches the problems of welding large size components in very thin thickness. This is a current program and although welding techniques have now been established, finished vessels have not yet been produced. The design ultimate strength in these vessels is 240,000 psi at room temperature and 330,000 psi at cryogenic temperature.

Manned Maneuverability Unit O_2 Bottle

A 16,900 psi burst strength 16.75 diameter x .200 wall vessel designed for 300,000 psi ultimate has been developed for Hamilton Standard. Two contracts on this program have been completed including two hydroburst tests which demonstrated 17,200 psi and 17,080 psi. A follow-on contract for eight more units bringing the total contracted to 24 has been completed.

Bu Weps Materials Investigation

A continuing program is in progress to evaluate the effect of chemistry variations on strength level and notch toughness. The materials under consideration include the 300 series stainless family. Results to date have identified chemical compositions which will offer biaxial strength levels in excess of 350,000 psi. Further

effort on this program will lead to demonstration in welded pressure vessels.

Apollo O_2 Back Pack Bottle

A cylindrical bottle 3 3/4" diameter, 17" long and .030 wall, intended for the back pack life support unit has been developed, delivered and qualified for Hamilton Standard. These vessels have met all program objectives. As of the present time, a current program is under way for a new design to meet revised envelope and operational requirements.

Hydrogen Dewar Vessel

39 inch cylinders are currently being produced for Bendix for use as an inner vessel in a hydrogen dewar. A special heat of low silicon 301 material was utilized because of the improved notch properties of low silicon materials at liquid hydrogen temperatures (-423°F).

Post Boost Control System

Work has commenced for Aerojet General on a conospheroid featuring compatibility with N_2O_4 and Hydrazine, high strength, and integration with the Arde multi-cycle metallic expulsion bladder.

The ARDEFORM process for manufacturing pressure vessels makes use of the capacity of austenitic stainless steel to gain strength when worked cold, a strength resulting from the transformation of metastable austenite to martensite during straining at low temperature. In the ARDEFORM process, this phenomenon occurs when the vessels are expanded into shape in a bath of liquid nitrogen (temperature -320°F).

Each ARDEFORM vessel first takes shape as a preform, an undersized vessel fabricated of an austenitic stainless steel. Fabrication of the preform before the steel is work-hardened permits the machining, shaping and welding of the components of the preform by conventional methods. The preform is submerged in the cryogenic nitrogen bath and stretched by internal pressurization to yield the desired final size, strength and configuration.

In the cryogenic stretch forming process, the vessel preform may be constructed from flat sheets, simple cones, and rolled and welded cylinders, eliminating the need for expensive forgings, tooling and extensive machining usually associated with existing manufacturing techniques.

The preform is frequently a composite of several geometric shapes. Because of the tendency of different sections of a vessel preform to stretch to varying magnitudes, the preform is designed to achieve the desired final vessel shape. For example, different stretch rates of heads and cylindrical sections of a preform sometime requires that the preform have a cylindrical section smaller in diameter than the ends.

Since in cryogenic stretch-forming, the final size and shape, as well as strength level, are achieved simultaneously, the preform must stretch directly to the final shape. To accomplish this stretching, certain design criteria must be met. For example, in the fabrication of spheres, if one desires to incorporate a boss or a thickened ring, the boss or ring is designed to stretch uniformly with the sphere body.

Arde, Inc. has developed plasticity design techniques that have been programmed for computer use. These computer programs enable ARDE designers to define integral preform shapes that will stretch to the desired final configuration.

In addition to integrally stretching the configurational components of a pressure vessel, the technique of adding attachments and other features by welding after stretching is available. This procedure is used to meet requirements for a local heavy section of such design as to be compatible with the stretch-forming technique. Such requirements would include a solid boss in a spherical vessel or a local thickened circumferential ring in a cylindrical vessel. With this modified technique, portions of a stretched vessel may be cut away and the required sections added. Welding after stretching, however, anneals the weld material and the material adjacent to the weld to very low strength levels. This situation is corrected by restretching these areas to bring them up to the strength level of the main body of the pressure vessel. The restretch is generally carried out at a pressure level equal to the original stretch pressure. Hence, no yielding will occur except in the local annealed regions of the attachments.

The effort on this program was directed along two parallel paths in the fabrication of pressure vessels.

1) Application of the aforesaid current Ardeform fabrication techniques to demonstrate the feasibility of utilizing cryogenically stretch formed vessels for the helium bottles of the lox tanks of the Saturn V, S-1C vehicle.
2) Determination of the feasibility of, and development of the methods for producing integral head bottles with spun-over ends, preferably utilizing seamless tubing, in conjunction with the Ardeform process.

In both cases, it was desirable to provide the process parameters required for obtaining maximum consistent properties commensurate with a low rejection rate during manufacture.

Hence, the program was divided into phases as described below:

Phase I - Process development for cryogenically stretching heavy gage 301 stainless steel.

This phase consisted of the selection of material of such a chemical composition and cleanliness that optimum mechanical properties under cryogenic (-320°F) strain would result. Furthermore, weld parameters would be established for obtaining joints which could be stretched to a maximum stress level at cryogenic temperature. An investigation toward the improvement of the composition of weld beads to make them more nearly equivalent to the composition of the base metal would be undertaken. To this end, it was necessary to establish an optimum stress level to which components could consistently be exposed without failure.

Additionally, eighty-two (82) uniaxial specimens were to be cryogenically stretched and tested in order to predict tensile and yield strengths, elongation, and notch strength for both welded and unwelded material at room temperature as well as at -320°F.

The stress corrosion resistance of cryogenically prestrained Ardeform material was also to be determined during this phase of the program. Specimens would be prepared, prestrained cryogenically, and stressed in a bent beam fixture for placement in a salt solution.

The feasibility of spinning over the ends of seamless or welded tubing was to be determined, for the purpose of fabricating an integral preform for a vessel. The vessel would then be cryogenicall strained to the optimum stress level established through the mechanical testing program.

Limited design effort was planned to permit the fabrication of subscale helium bottles. A L/D ratio in the range of 3 to 5 and a minimum diameter of 10 inches were specified, in addition to operational and test pressures corresponding to those of the full scale vessels.

Phase II - Manufacture of subscale 301 stainless steel bottles.

The fabrication and cryogenic stretching of 3 each of the following subscale bottles was to be accomplished in this phase of the program.

a) Roll and welded bottle, fabricated from rolled flat sheet stock and hydroformed heads.

b) Integral head bottle, fabricated from seamless tubing with spun-over ends.

One each of these type vessels was committed to cryogenic burst testing by Arde-Portland. Two each would be delivered to NASA.

III SUMMARY

The high pressure bottle configuration used in the LOX tanks of the Saturn V, S1C vehicle, were duplicated in a subscale version using the Ardeform process. The objectives of the program were to demonstrate the feasibility of using cryogenically stretch formed 301 stainless steel tanks for such space vehicle applications, and to provide the process parameters required for obtaining maximum consistent properties commensurate with a low rejection rate during manufacture.

In order to achieve these objectives, the effort on the program was directed along several parallel paths.

1) Demonstrate the feasibility of fabrication of Ardeform pressure vessels for high pressure helium gas storage.
   a) Welded configuration-- Develop 100% weld efficiency in 1/4" thick material in a subscale vessel.
   b) Integral Head Configuration-- Develop floturning and head spinning processes for use with standard grade Ardeform material in a subscale vessel.

2) Provide material properties data through a materials testing program for parent material as well as welded material.
   a) Yield strength
   b) Notch toughness
   c) Resistance to stress corrosion

This report contains the results of the development work outlined above. The fabrication technology employed is discussed, as well as the metallurgical investigations in support of this work. The results of tests on both specimens and vessels are reported and discussed in detail in the body of the report.

<u>ARDEFORM PRESSURE VESSELS</u>

S/N 2 Roll & Weld Vessel

Fabricated with Rolled Sheet,
Hydroformed Heads, Machined Bosses

S/N US-2 Integral Head Vessel

Seamless Vessel with Integral Hot Spun Heads
Machined Bosses, Welded in Place

FIG. 1

Design parameters were established to represent conditions in a full scale vessel. Pressures were established to correspond with the following full scale vessel pressures at -320°F.

Working	3300 psi
Proof	4500 psi
Burst	6600 psi

Size requirements for the subscale vessels were set as follows:

L/D of 3 to 5

10" min. diameter

Thickness Ratio: $\frac{\text{Full Scale}}{\text{Subscale}} = 1$

A double vacuum melted Arde standard composition of 301 stainless steel was selected to provide increased notch toughness, high strength cleanliness, and minimum flaw sizes. The material was metallurgically evaluated prior to commitment for fabrication.

The weld development program was undertaken with flat 1/4" plate material to develop the following weld parameters: heat settings, feed speeds, weld preparations, filler rod size, and weld bead control. Two approaches were investigated; double pass welding and single pass welding. Single pass was selected over the conventional double pass technique because of less chance of lack of fusion between passes and reduced carbide growth. Problems encountered were under cutting, sagging, and drop-through. "3 o'clock" welding, where the torch is held horizontal, was investigated as a means of solving these problems. After testing of a verification vessel (S/N 2), this form of welding was discarded in favor of single pass Tig, pressurized gas back-up welding.

Metallurgical investigation was performed on tensile specimens fabricated from the heat of material used for the welded vessel fabrication. These specimens were in tensile test bar form, consisting both of parent metal and weldments of 301 composition. Eighty-seven (87) specimens were cryogenically prestressed in liquid nitrogen at a selected stress level of 235,000 psi. After prestressing, the entire group was divided into smaller groups for testing at room temperature and -320°F for both welded and welded specimens. Half of the specimens were used for plane strain fracture toughness testing. The effect of material rolling direction on the specimens was also observed. Fracture toughness values were determined on center notch partial thickness specimens of the prescribed dimensions established by the ASTM Fracture Toughness Subcommittee. These values were further substantiated by testing identical material using the single edge notch tensile specimen and determining "pop in" load by the electrical potential method. A brief summary of results follows:

1. Room Temperature Results

   Parent Material

   220.2 KSI Average Yield

   12.2% Average Elongation - Parallel Specimens

   11.5% Average Elongation - Transverse Specimens

   102.6 KSI $\sqrt{IN}$ Average K_{IC} (Center Notch)

   106.8 KSI $\sqrt{IN}$ Average K_{IC} (Single Edge Notch)

   Weld Bead

   218.6 KSI Average Yield

   103.6 KSI $\sqrt{IN}$ Average K_{IC} (Center Notch)

2. -320°F Results

- Parent Material
  - 302.3 KSI Average Yield
  - 10.6% Average Elongation - Parallel Specimens
  - 10.0% Average Elongation - Transverse Specimens
  - 83.9 KSI $\sqrt{IN}$ Average K_{IC}

- Weld Bead
  - 298.8 KSI Average Yield
  - 86.7 KSI $\sqrt{IN}$ Average K_{IC}

Eight (8) tensile specimens were cryogenically prestressed to 232,000 psi and then loaded in a bent beam specimen holder at 184,000 psi at room temperature. The specimens were placed in a .75 normal salt solution for five months, with the following results:

- No indications of stress corrosion
- One specimen pulled to Room Temperature failure at 228 KSI
- One specimen pulled to -320°F failure at 300 KSI

Fabrication of the welded vessels was accomplished using standard rolling, hydroforming, and machining techniques. All processes were controlled through Arde specifications. These vessels simulated full scale vessel welding through the incorporation of three girth welds, two diametrally opposed longitudinal welds, and two boss to head welds. Three vessels were cryogenically stretch formed. Two were delivered to NASA - MSFC for evaluation and one was cryogenically burst tested at Arde-Portland at 10,850 psi. This represented 337,000 psi nominal hoop stress.

In the integral head vessel fabrication, billets were converted to forgings. The forgings were then floturned to seamless cylinders. In the course of this development phase, the first unit failed in process at 50% cold reduction after five successive floturning passes without annealing. Therefore, interpass annealing was instituted on the remaining parts after each third pass. (approximately 30% cold reduction)

Each cylinder, therefore, received three interpass anneals during processing. The next four cylinders were successfully floturned using this method.

Hot spinning of integral heads on the seamless cylinders was accomplished with both one and two pass operations at a single temperature. Four cylinders were completed with 46% - 56% usable closures using this method. However, tracer machining was required on both the inside and outside of the heads to remove heavy surface cracks. Through-cracks at the edge of the boss opening were removed by machining larger boss openings. After welding the bosses in place, the parts were annealed, cleaned, and cryogenically stretch formed. Two vessels were forwarded to NASA-MSFC and one was cryogenically burst tested at Arde-Portland. 316,000 psi nominal hoop stress was developed at the burst pressure of 10,175 psi.

TABLE I - VESSEL SUMMARY

ROLL AND WELD VESSEL -D3433

S/N	Forming Pressure	Forming Stress	Weight	Volume	Disposition
1	10,000 psig	254.1 ksi nom. 307.4 ksi true	92.4 lbs	-	Cryogenic burst tested to 10,850 psi 337.0 ksi nominal hoop stress 345.9 ksi true hoop stress
2	4,000 psig	101.5 ksi nom.	-	-	Bad weld - hold in stores
3	10,000 psig	263.9 ksi nom. 306.6 ksi true	92.1 lbs	2.24 cu.ft. 3868 cu.in.	Shipped to MSFC
4	10,000 psig	263.6 ksi nom. 306.7 ksi true	91.7 lbs	2.27 cu.ft. 3931 cu.in.	Shipped to MSFC

INTEGRAL HEAD VESSEL - D3435

S/N	Forming Pressure	Forming Stress*	Weight	Volume	Disposition
US-2	9,300 psig	272.6 ksi nom. 316.1 ksi true	112 lbs.	3.28 cu.ft. 5667 cu.in.	Shipped to MSFC
US-5	9,350 psig	252.3 ksi nom. 306.9 ksi true	108 lbs.	3.1 cu.ft. 5366 cu.in.	Shipped to MSFC
CF-10	10,175 psig	272.3 ksi nom. 332.1 ksi true	-	-	Cryogenic burst tested to 10,300 psig 316.3 ksi nominal hoop stress 375.9 ksi true hoop stress

$$\text{Nominal Hoop Stress} = \frac{\text{Pressure X Original Radius}}{\text{Original Thickness}}$$

$$\text{True Hoop Stress} = \frac{\text{Pressure X Final Radius}}{\text{Final Thickness}}$$

* Forming stresses calculated using a reduced wall thickness. Repair grinding by Parsons Corp. on tube I.D.'s resulted in locally reduced wall thicknesses by .015 on US-5 and CF-10 and by .033 on US-2. Using the wall thickness without consideration of reduced sections, reduces the forming stress by approximately 20 ksi on US-5 and CF-10, and 40 ksi on US-2.

SECTION IV PROCESS DEVELOPMENT FOR CRYOGENICALLY STRETCHING HEAVY GAGE 301 STAINLESS STEEL (PHASE I)

A. Material Selection and Evaluation

1. Material Selection

The metallurgical design of a type 301 stainless steel was undertaken as a primary step in the program. Optimum mechanical properties for cryogenic prestraining was of utmost importance. In order to insure the highest possible quality, the basic material was specified as induction vacuum melted from high purity raw material, followed by a consumable electrode vacuum remelt. Double vacuum melting of a material refines it in successive steps. This process provides increased notch toughness thru the reduction of oxygen and hydrogen content. Flaw sizes are minimized first through use of high purity raw material during the initial induction melt and during the consumable remelting. A far cleaner steel with very high strength and excellent notch properties is produced in this manner.

One heat of steel was ordered for conversion to billets, sheet bar, and sheet stock in accordance with Arde specifications, controlling chemistry as well as cleanliness. Billets were intended for conversion to forgings for the production of seamless cylinders. These would then be utilized in the fabrication of the integral head vessel. Sheet stock was for use in the mechanical testing program as well as for welded vessel fabrication. Sheet bar was for boss material.

It became evident just prior to delivery of the raw material, that the supplier (Allegheny-Ludlum Steel Corp.) was in fact delivering three separate heats of material rather than a single

heat. The specified chemistry, as well as the actual received is shown in Table II. It should be noted that the hydrogen content of Heat 7-2067 exceeded the specified 2 parts per million by 0.7 ppm. Through MRB action, the heat was accepted for use, inasmuch as 2 ppm is an ideal value for sheet stock; whereas, a value of 5 ppm is a realistic value for billets prior to conversion. This value of 5 ppm would normally be reduced to the level of 2 ppm through reduction of the material thickness in the sheet stock rolling process.

2. Material Evaluation

Upon arrival of the steel from the vendor, Arde evaluation commenced prior to committing the material to use. Chemical analysis was checked against the specification (See Table II). Inclusion content was determined metallographically, and compared against specified allowables as defined by ASTM E-45-51, and set forth in Arde Specification 0015. It is worthy of note that the three heats delivered had a lower inclusion content than the specification allowable in all cases. (See Table III) Cleanliness and grain structure may be seen in Figures 2, 3 and 4.

Tensile specimens were prepared (see Figure 5), and a number of tests performed under varying conditions. A review of the data shown in Table IV - VI will indicate the effect of different pretreatments as well as intermediate treatments. All specimens, save one, were annealed, pickled, and passivated, in order to duplicate the processing to be actually accomplished during vessel fabrication. Stress-strain curves are shown in Figures 6 - 11.

Table IV shows the results of material evaluation uniaxial tensile tests on heat 8606B. This heat provided all of the sheet stock used for welded vessels in this program.

Table V shows uniaxial tensile test results for evaluation of heat 7-2067. This material was used in the production of seamless vessels US-1 through US-5. Specimen 1A was taken from a processed tube in order to verify the strain response of the material in the form that it would be stretched.

Table VI shows the same test data for heat 7-2099 used to fabricate seamless vessels CF-6 through CF-10.

Carbide present in large quantities in the material made it necessary to plan on annealing the vessels prior to cryogenic stretch forming.

TABLE II

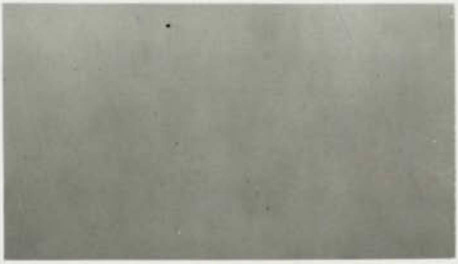
CHEMICAL ANALYSIS

	Specification (Arde 0015-0017)	Heat 8606B (Sheet)	Heat 7-2067 (Billets)	Heat 7-2099 (Billets)	Heat 8606A (Sheet Bar)
Carbon	.055 - .075	.065	.060	.060	.065
Manganese	1.00 - 1.70	1.30	1.22	1.31	1.30
Silicon	.30 - .70	.41	.41	.57	.41
Chromium	17.00 - 17.50	17.02	17.20	17.20	17.02
Nickel	7.30 - 7.60	7.57	7.63	7.43	7.57
Nitrogen	.02 - .04	.037	.04	.027	.037
Phosphorous	.015 max.	< .01	< .01	< .01	< .01
Sulfur	.015 max.	.006	.004	.003	.006
Oxygen	60 ppm max.	30 ppm	30 ppm	44 ppm	30 ppm
Hydrogen	2 ppm max.	1 ppm	<2 ppm	2.7 ppm	1 ppm

TABLE III

INCLUSION CONTENT

Inclusion Types	Allowable Inclusions (ASTM E-45-51)	Actual		
		Sheet (Welded Vessel)	Billet (Integral Vessel)	
		Heat 8606B	Heat 7-2067	Heat 7-2099
Sulfide	2 Thin	0	0	0
Alumina	1 Thin	0	0	0
Silicate	3 Thin	0	0	0
Globular Oxide	2 Thin/1 Heavy	0/0	1.5/0	1.5/0
Titanium Carbonitrate	2 Thin/1 Heavy	0/0	2/0	0/0



Heat 8606-B Cleanliness

100 X

Heat 8606-B Grain Structure

100 X

FIG. 2

Heat 7-2099 Cleanliness

100 X

Heat 7-2099 Grain Structure

100 X

FIG. 3

MATERIALS EVALUATION

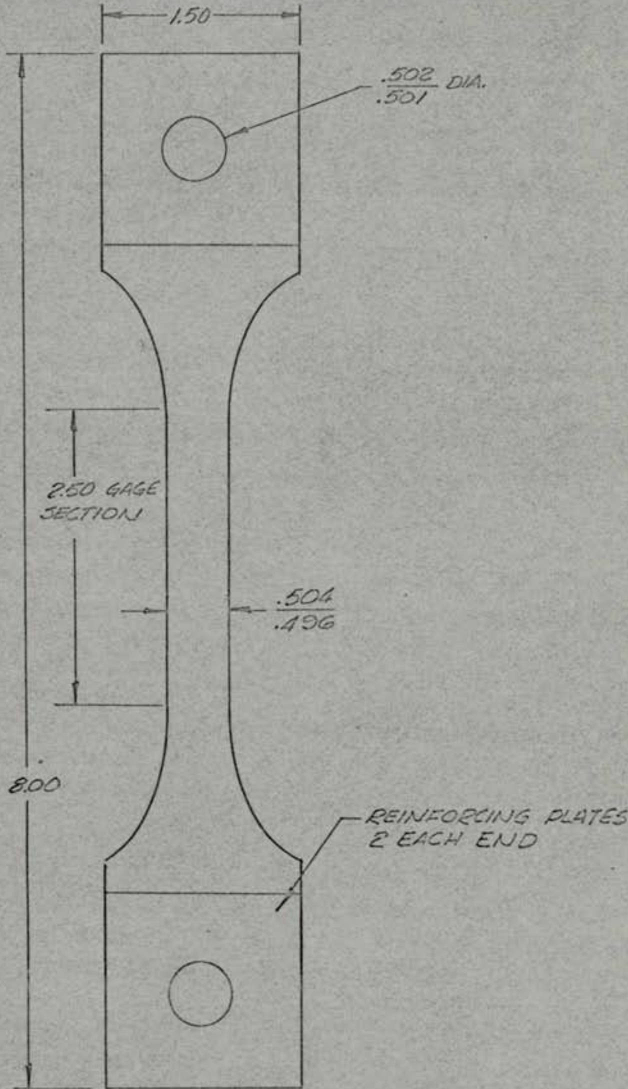
Heat 8606-A   Cleanliness

100 X

Heat 8606-A   Grain Structure

100 X

FIG. 4



TENSILE SPECIMEN

FIGURE 5

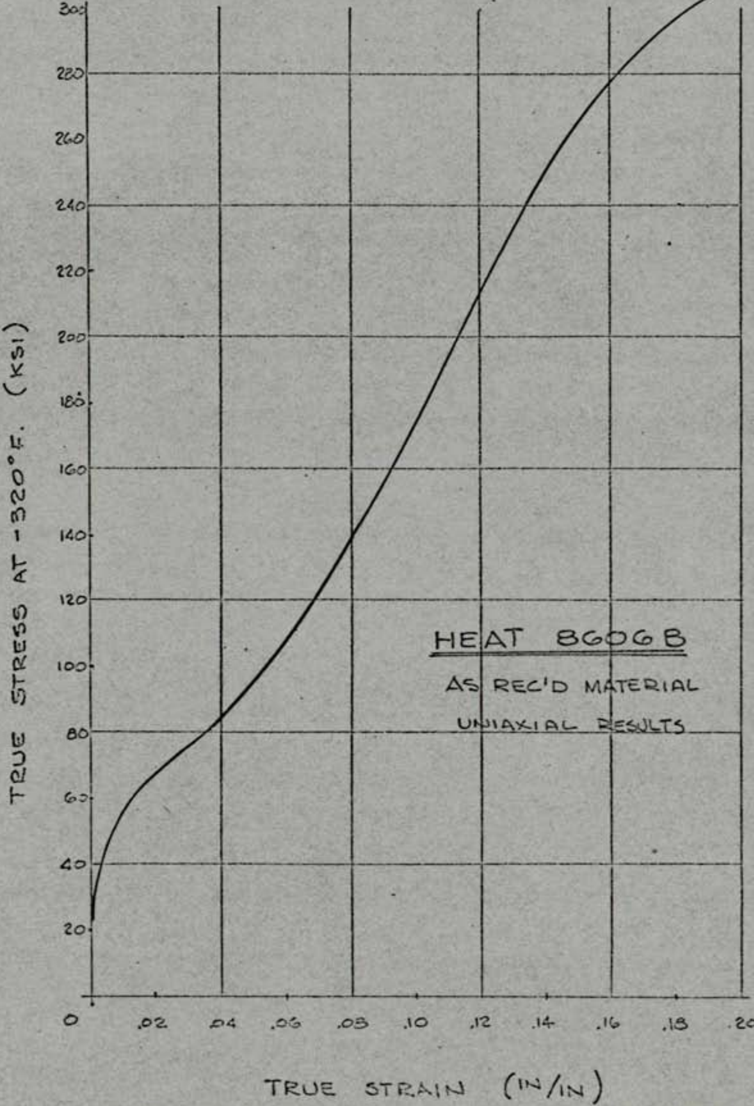

TRUE STRESS AT -320°F. (KSI)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
TRUE STRAIN (IN/IN)
HEAT 8606B
AS REC'D MATERIAL
UNIAXIAL RESULTS

FIGURE 6

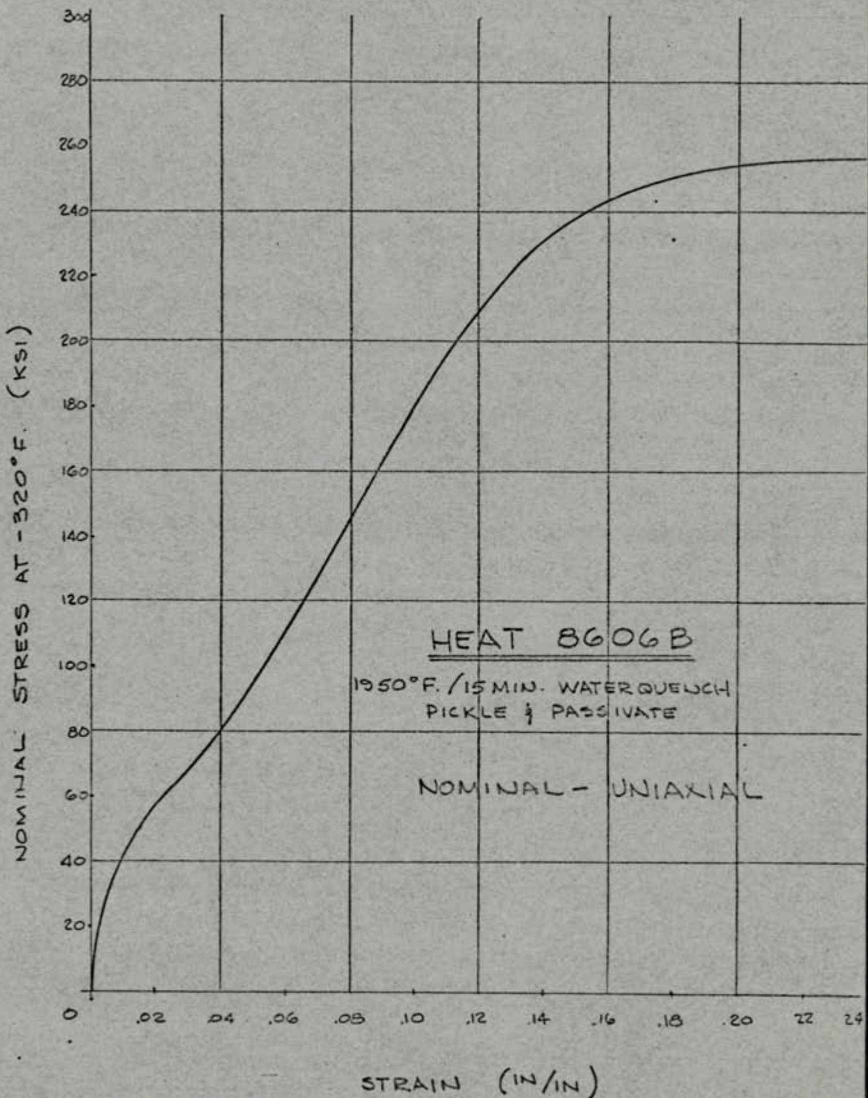

300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
NOMINAL STRESS AT -320°F. (KSI)
STRAIN (IN/IN)
HEAT 8606B
1950°F. /15 MIN. WATER QUENCH
PICKLE & PASSIVATE
NOMINAL - UNIAXIAL

FIGURE 7

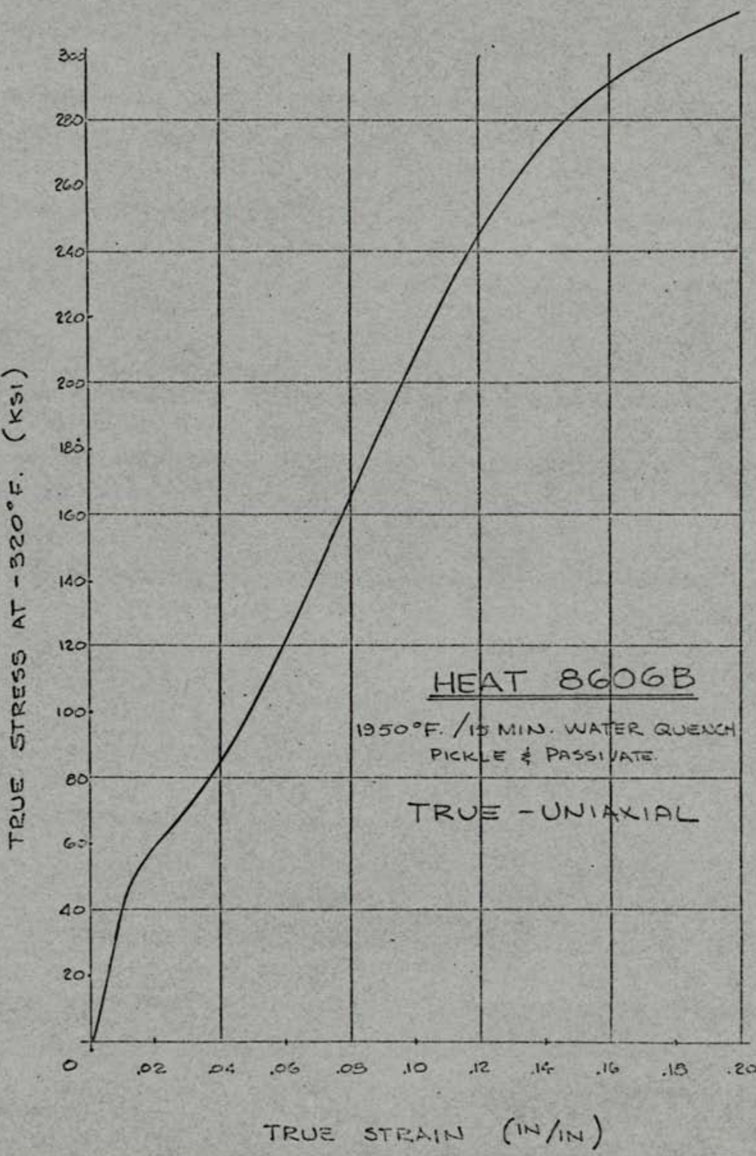

300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
TRUE STRESS AT -320°F. (KSI)
TRUE STRAIN (IN/IN)
HEAT 8606B
1950°F. /15 MIN. WATER QUENCH
PICKLE & PASSIVATE
TRUE - UNIAXIAL

FIGURE 8

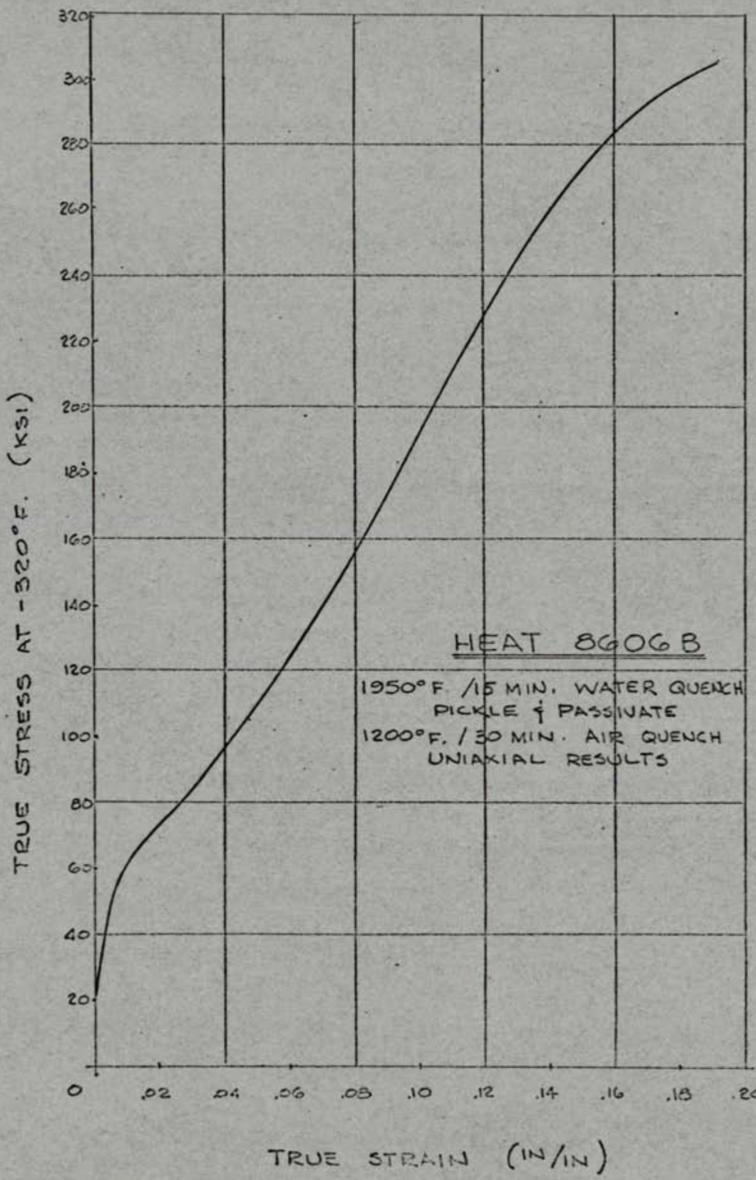

320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
TRUE STRESS AT -320°F. (KSI)
TRUE STRAIN (IN/IN)
HEAT 8606 B
1950°F /15 MIN. WATER QUENCH
PICKLE & PASSIVATE
1200°F. / 30 MIN. AIR QUENCH
UNIAXIAL RESULTS

FIGURE 9

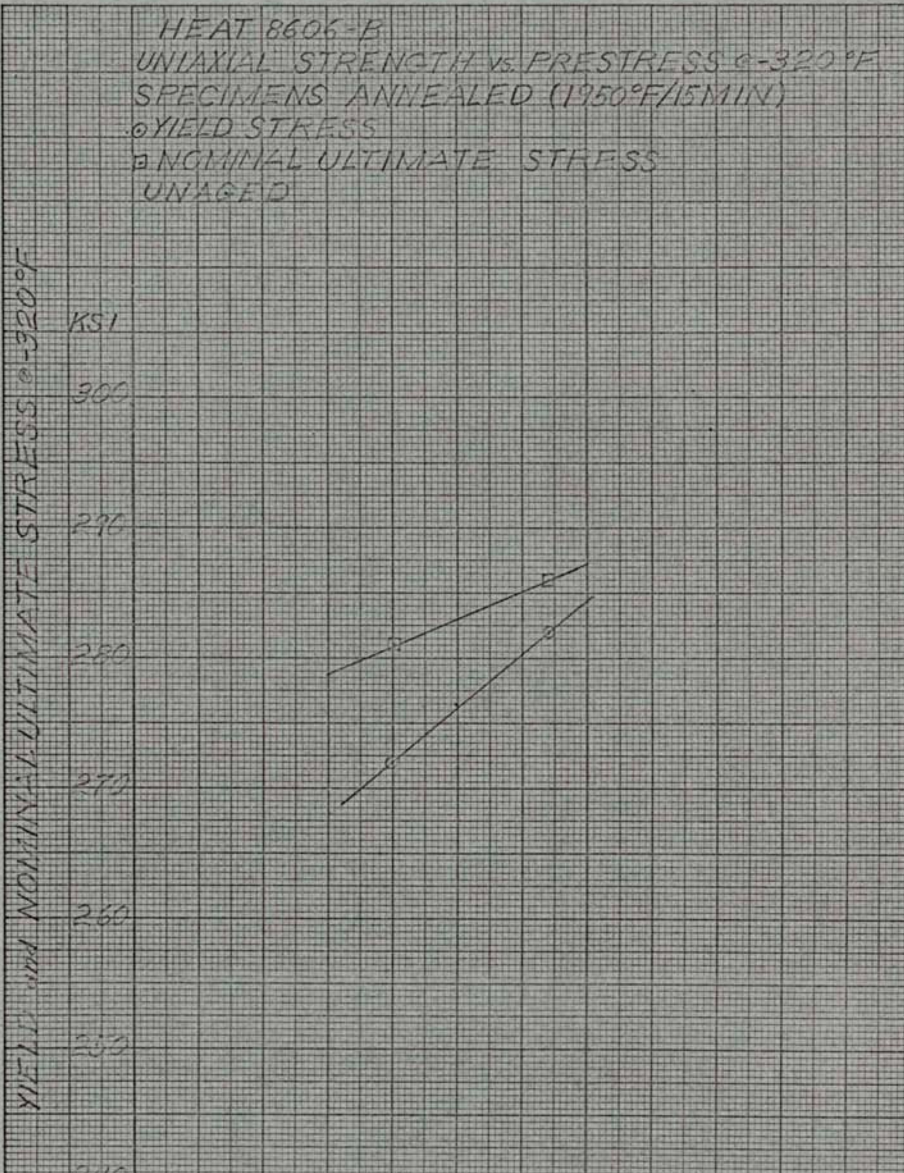

HEAT 8606-B
UNIAXIAL STRENGTH vs. PRESTRESS @-320°F
SPECIMENS ANNEALED (1950°F/15MIN)
⊙ YIELD STRESS
⊡ NOMINAL ULTIMATE STRESS
UNAGED
YIELD and NOMINAL ULTIMATE STRESS @-320°F
KSI
300
290
280
270
260
240
220
270 KSI
ε PRESTRESS @-320°F

FIGURE 10

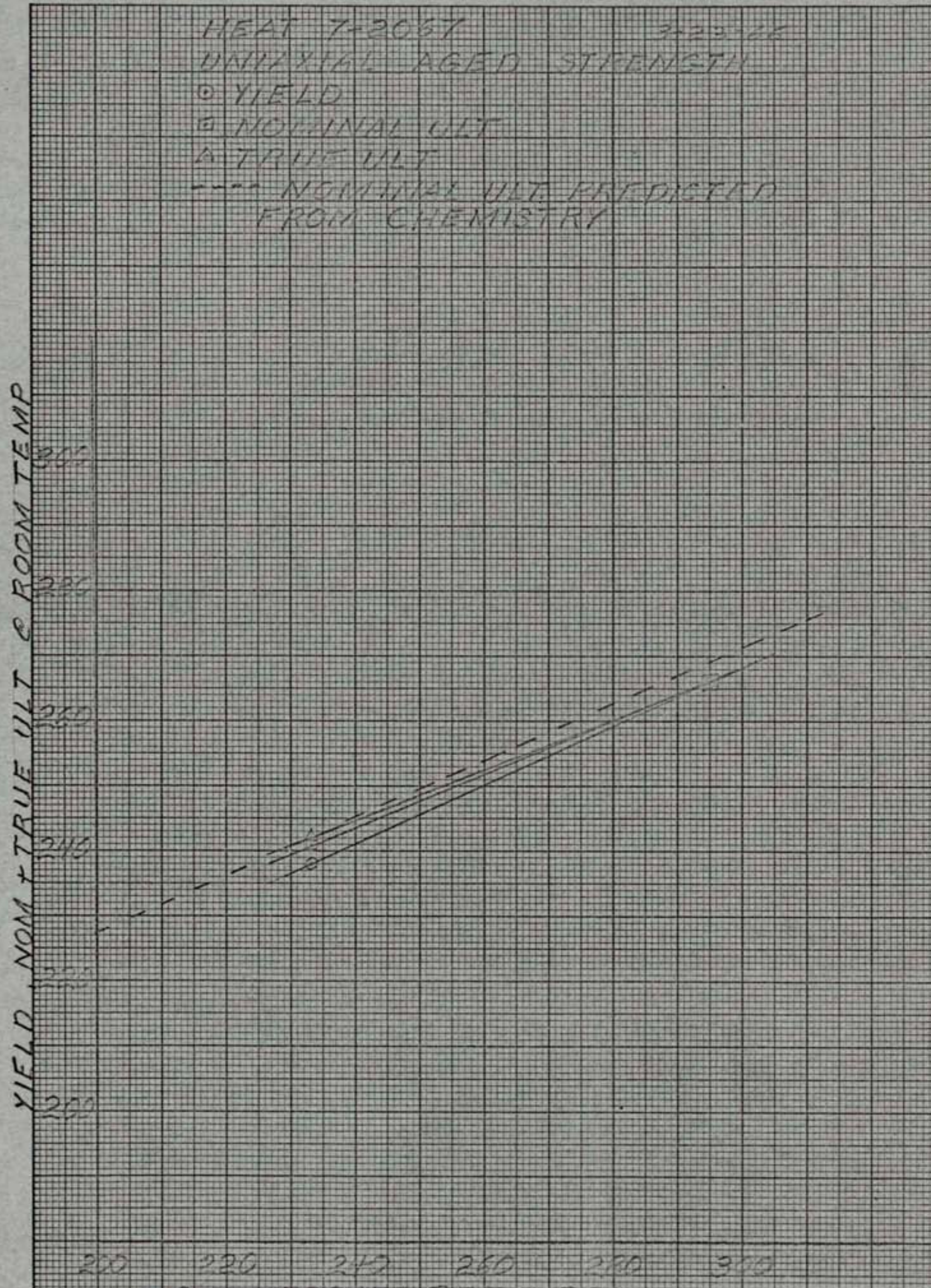

HEAT 7-2067
UNIAXIAL AGED STRENGTH
⊙ YIELD
⊡ NOMINAL ULT
△ TRUE ULT
---- NOMINAL ULT PREDICTED
FROM CHEMISTRY
YIELD, NOM + TRUE ULT @ ROOM TEMP
200
220
240
260
280
300
200
220
240
260
280
300

FIGURE 11

TABLE IV

TEST RESULTS - HEAT 8606B

MATERIAL EVALUATION

Specimen Number	-320°F Prestrain Condition: Condition	% Elongation in 2 Inches	Nominal Stress KSI	Intermediate Heat Treatment	Final Test to Failure: % Elongation in 2 Inches	Nominal Ultimate Tensile Strength (KSI)	Test Temperature	Remarks
1	As Rec'd.	21	246	-	-	246	-320°F	
2	Annealed	23	253	-	-	253	-320°F	
3	Anneal & Heat Treat	21	250	-	-	250	-320°F	BOGL
4C	Annealed	16	235	-	-	235	-320°F	
4	Annealed	13.7	232	-	1.6	286	-320°F	BOGL
5	Annealed	13	225	-	7.2	281	-320°F	BOGL- Yielded in Prestrain
6	Annealed	16	244	-	1.1	274	-320°F	BOGL- Yielded in Prestrain
1C	Annealed	14	232	-	1.5	218	Room	BOGL
3C	Annealed	16	235	790°F/20hrs	1.1	237	Room	
4D	Annealed	12	214	790°F/20hrs	1.05	228	Room	
5A	Annealed	14	240	790°F/20hrs	1.2	244	Room	
1CN2	As Rec'd.	-	233	-	-	301	-320°F	4 mos. in salt bath @
2CN1	As Rec'd.	-	233	-	-	228	Room	184 KSI stress prior to failure pull

TABLE V

TEST RESULTS - HEAT 7-2067

MATERIAL EVALUATION

	-320°F Prestrain Condition				Final Test to Failure			
Specimen Number	Condition	% Elongation in 2 Inches	Nominal Stress KSI	Intermediate Heat Treatment	% Elongation in 2 Inches	Nominal Ultimate Tensile Strength (KSI)	Test Temperature	Remarks
1	As Rec'd.	25	260	-	-	260	-320°F	
1A	Annealed	20	270	-	-	270	-320°F	Taken from floturned tube S/N US-1
1B	As Rec'd.	28	258	-	-	258	-320°F	
2	As Rec'd.	12.5	210	790°F/20 hrs	5.5	240	Room	
3	As Rec'd.	20	252	790°F/20 hrs	1.1	266	Room	

TABLE VI

TEST RESULTS - HEAT 7-2099

MATERIAL EVALUATION

	-320°F Prestrain Condition				Final Test to Failure			
Specimen Number	Condition	% Elongation in 2 Inches	Nominal Stress KSI	Intermediate Heat Treatment	% Elongation in 2 Inches	Nominal Ultimate Tensile Strength (KSI)	Test Temperature	Remarks
1	As Rec'd.	20.5	276	-	-	276	-320°F	
2	As Rec'd.	12.7	223	790°F/20 hrs	2	256	Room	
3	As Rec'd.	20.	264	790°F/20 hrs	1.8	286	Room	

B. Establishment of Welding Parameters

Investigation was directed toward the improvement of weld bead composition, in order to make the weld joint strength more nearly equivalent to the parent material strength. It was, therefore, necessary to establish weld parameters for obtaining joints which were capable of being stretched to a maximum stress level at cryogenic temperature (-320°F).

Welds produced in a single pass were deemed advantageous for several reasons rather than the conventional double-pass approach. The single pass technique reduces carbide precipitation immediately adjacent to the weld bead. This reduction was known to greatly enhance the cryogenic stretch properties of the material. It also would eliminate lack of fusion between passes frequently experienced in multi-pass welds. Also, a single pass weld would reduce the amount of filler material introduced into the joint. In this particular program, carbide growth was not important since all vessels would be annealed because of the previously mentioned high carbide content in the material.

The development program consisted of three phases: conventional horizontal welding with a vertical torch, "three o'clock" welding with a horizontal torch, and horizontal welding with a closely controlled pressurized gas back-up and vertical torch. In all cases, the semi-automatic tungsten inert gas (TIG) welding process was used, with helium torch gas and argon back-up gas. Specific objectives were:

- Develop settings and speeds
- Establish weld joint preparation
- Determine filler rod size
- Determine carbide distribution
- Develop control of underbead as well as overbead
- Produce strong, stretchable welds

Phase 1 - Conventional Horizontal Welding

Effort in this phase was initiated with single pass welding on available 1/4" 301 stainless steel (See Figure 12). When heat 8606B became available, welds were made in the .220 inch thick material. Both single and double pass welds were checked in order to verify the choice of single pass welding (See Figures 13 and 14). Various joint designs and welding parameters were utilized with this conventional vertical torch horizontal welding (See Figure 15). After producing thirty (30) samples, and reviewing them metallographically, it was determined that no combinations of the variables produced acceptable joints. Weldments either exhibited lack of penetration or drastic overbead concavity. Concavity resulted from gravity effects on the mass of molten metal. See Figures 16 and 17 for an example of this type of weld. Note the concavity and drop-through that is exhibited.

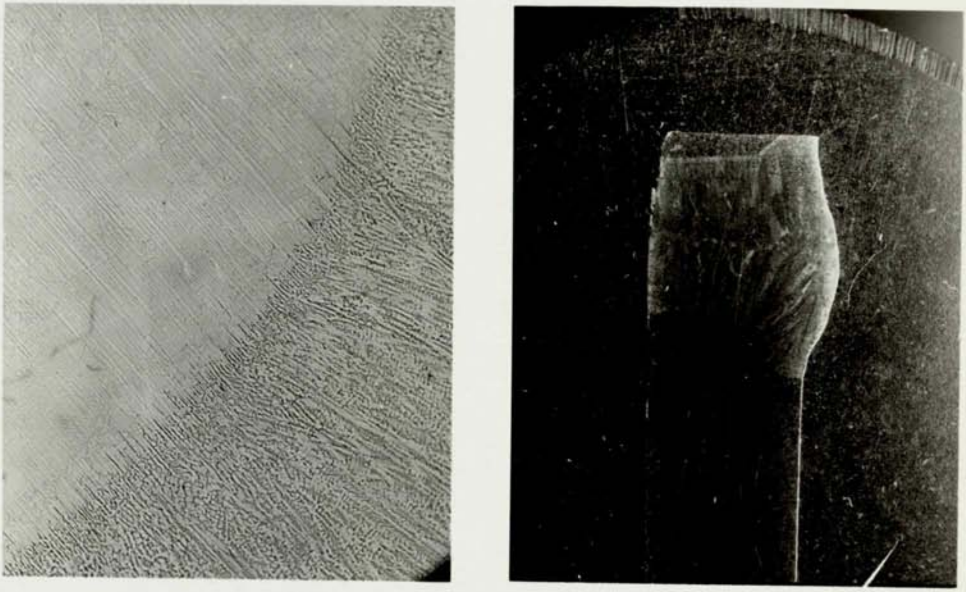
Phase 2 - "Three O'Cock" Welding

This method, where the torch is held in the horizontal position, (See Figure 16) was investigated as a means of reducing the effect of gravity on the weld. Joints shown in Figure 17 were produced with this method. Welds were generally more satisfactory than those made in Phase 1, except for occasional shallow undercuts on the upper edge of the fusion zone. Porosity was frequently present in the fusion zone as well.

Phase 3 - Vertical Welding with Pressurized Inert Gas Back-Up

Pressurized argon gas back-up was utilized to support the weight of the molten weld puddle. It was found that the required pressure could conveniently be controlled through the use of a manometer. This procedure produced excellent welds in both "V" joint weld and butt weld specimens (See Figures 16 and 17). Consequently, this method of welding was selected for the deliverable hardware in this program, with a 100% land weld preparation.

WELD DEVELOPMENT



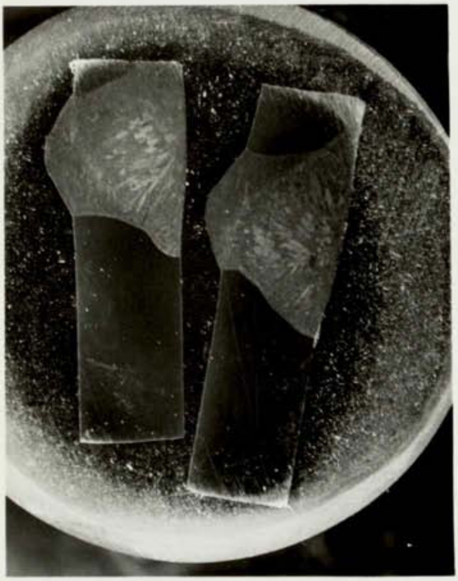
Mount 100X

SINGLE PASS WELD - 1/4" PLATE

301 STAINLESS STEEL

FIG. 12

WELD DEVELOPMENT



Mount 100X

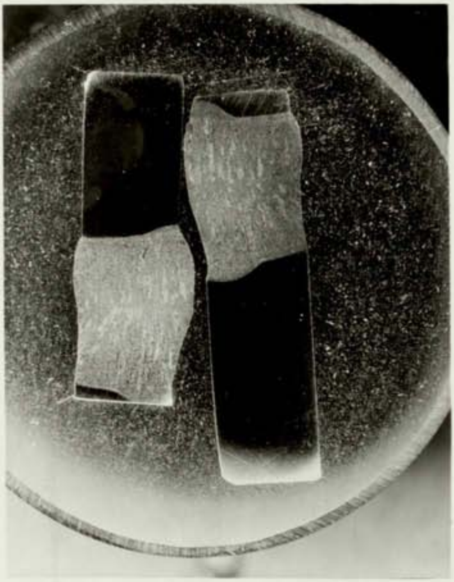
DOUBLE PASS WELD - BASE MATERIAL

ANNEALED PRIOR TO WELDING. .220

THICK PLATE HEAT 8606B

FIG. 13

WELD DEVELOPMENT

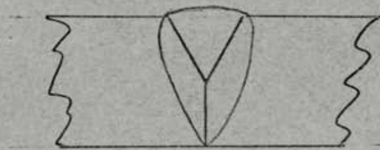


Mount 100X

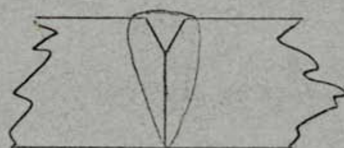
SINGLE PASS WELD - BASE MATERIAL
ANNEALED PRIOR TO WELDING .220
THICK PLATE HEAT 8606B

FIG. 14

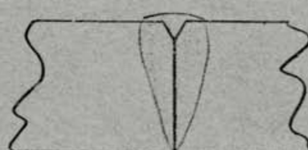
WELD PREPS UTILIZED IN PROGRAM



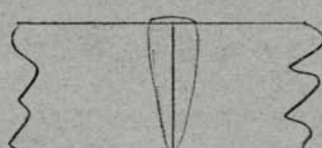
50% LAND



75% LAND

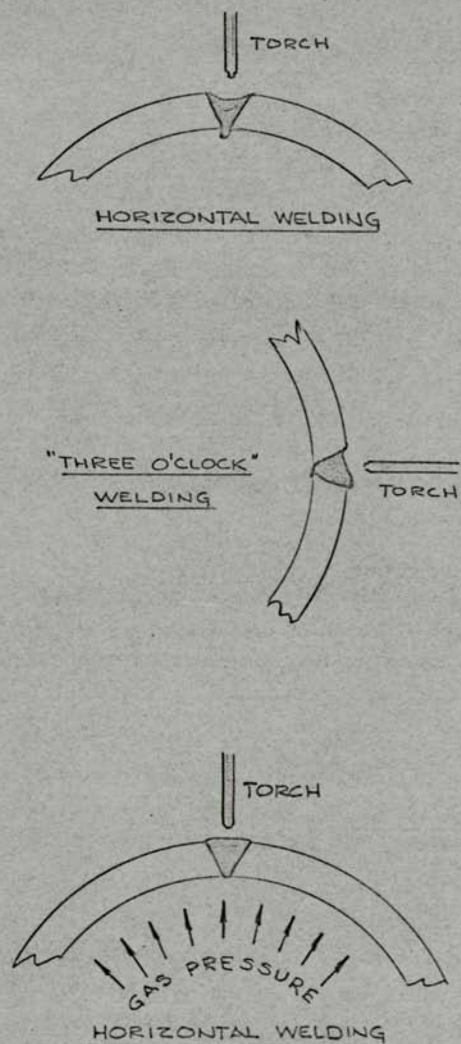


85% LAND



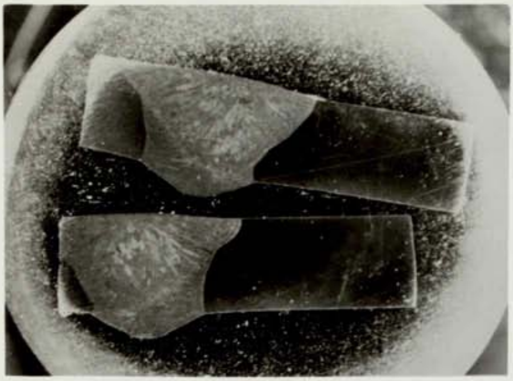
100% LAND

FIGURE 15



WELDING METHOD DEFINITIONS

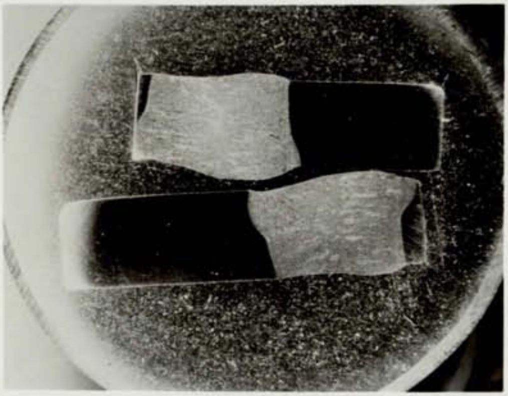
FIGURE 16



Horizontal

Double Pass Weld

Note Drop Thru



"3 o'clock" Single

Pass Weld

Note Sag

Horizontal Single Pass

Weld With Pressurized

Inert Gas Back-Up

FIG .17

C. Mechanical Testing

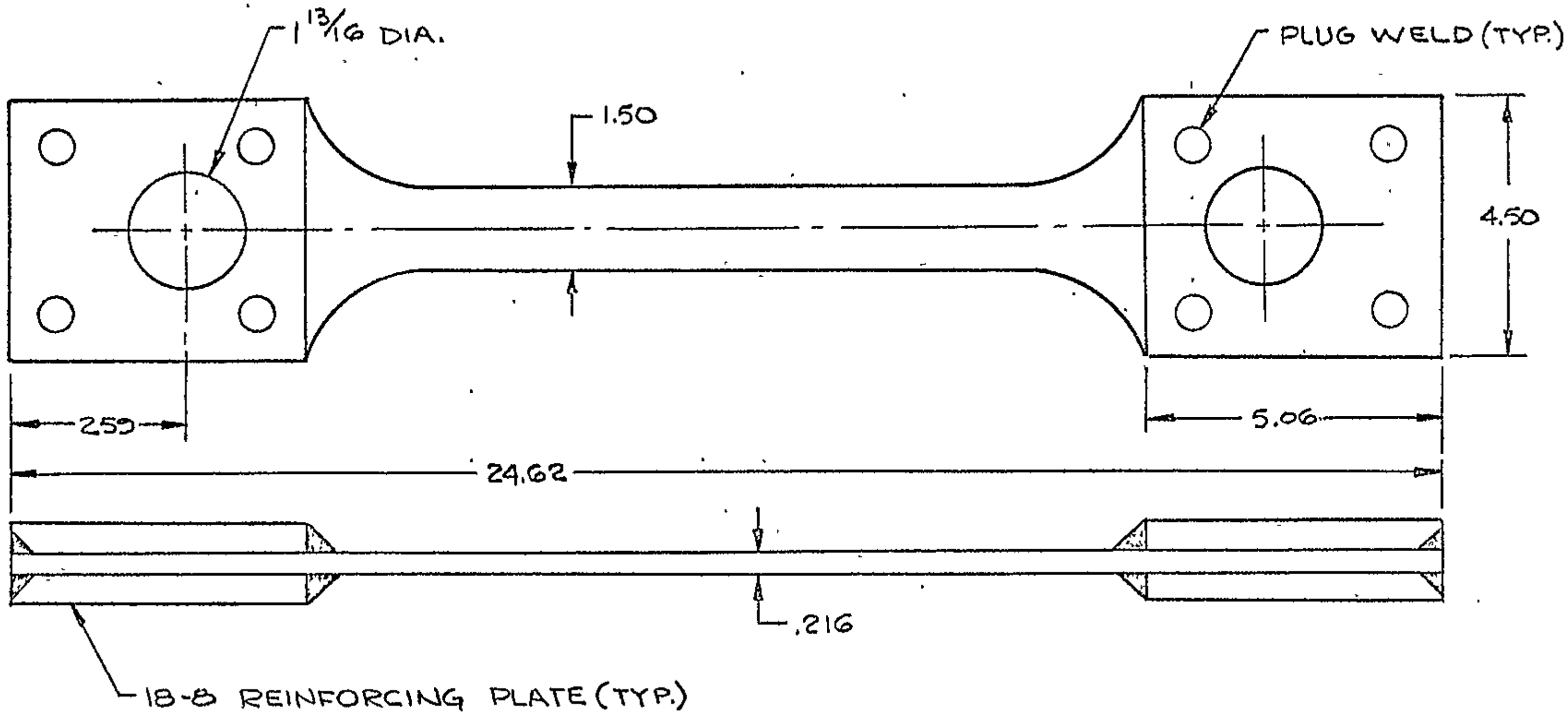
1. Structural and Notch Testing

Tensile specimens were fabricated for mechanical testing using rolled plate stock produced from heat 8606B. Specimens were cut both parallel (marked N1) and transverse (marked N2) to the rolling direction of the material. One-half of the specimens were welded across the gage section for evaluation of welded Ardeform material. These tensile specimen configurations are shown in Figures 18 and 19.

The welded specimens were fabricated with a centrally located 100% penetration single pass weld using 308 weld wire. The "3 o'clock" weld operation was performed to effect a straight butt joint weld. As noted in Section IV B some weld repairs were required to correct shallow undercutting. At this point in the program, pressurized gas back-up welding previously described had not been completely developed.

All specimens were annealed, pickled and passivated per Arde Specifications, and then shipped to Huntsville Division, Thiokol Chemical Corporation for cryogenic prestraining and testing.

Eighty-seven (87) samples were cryogenically prestressed in liquid nitrogen at a nominal stress level of 235,000 psi. After prestress, the entire group of specimens were equally subdivided into small groups for further testing in accordance with the schedule shown in Table VII.



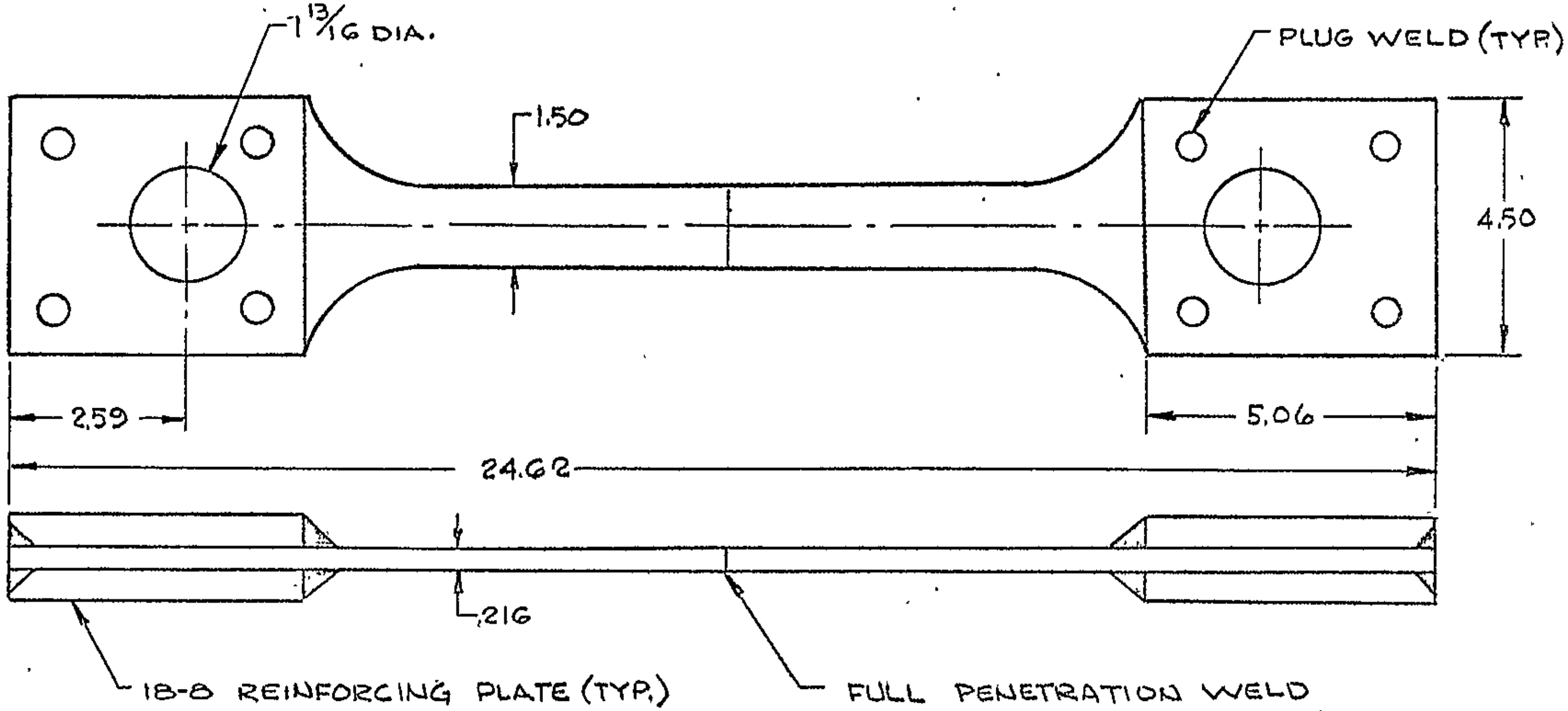
SMOOTH TENSILE SPECIMEN PREFORM

SKC 10002

FIGURE 18

ARDE-PORTLAND, INC.

REPORT NO.________ PREPARED BY________ DATE________ JOB NO.________ PAGE________



SMOOTH TENSILE SPECIMEN PREFORM

WELDED

SKC 10003

FIGURE 15

TABLE VII

MECHANICAL TESTING PROGRAM

SMOOTH TENSILE TESTING

Quantity	Part Number	Temp. of Test	Orientation	Material
6	SKC 10002N-1	-320	Longitudinal	Unwelded
6	SKC 10002N-2	-320	Transverse	Unwelded
5	SKC 10002N-1	Room Temp.	Longitudinal	Unwelded
6	SKC 10002N-2	Room Temp.	Transverse	Unwelded
5	SKC 10003N-1	-320	Longitudinal	Welded
5	SKC 10003N-2	-320	Transverse	Welded
5	SKC 10003N-1	Room Temp.	Longitudinal	Welded
5	SKC 10003N-2	Room Temp.	Transverse	Welded

NOTCHED TENSILE TESTING

Quantity	Part Number	Temp. of Test	Orientation	Material
6	SKC 10004N-1	-320	Longitudinal	Unwelded
6	SKC 10004N-2	-320	Transverse	Unwelded
6	SKC 10004N-1	Room Temp	Longitudinal	Unwelded
6	SKC 10004N-2	Room Temp.	Transverse	Unwelded
5	SKC 10005N-1	-320	Longitudinal	Welded
5	SKC 10005N-2	-320	Transverse	Welded
5	SKC 10005N-1	Room Temp.	Longitudinal	Welded
5	SKC 10005N-2	Room Temp.	Transverse	Welded

The load value, elongation, and stress level data determined during the prestressing operations of these specimens are shown on Tables VIII through XV. It is evident from these data that the desired level of stress, 235,000 psi, was established in each specimen resulting in reasonably uniform elongation (10 to 12 percent) of the gauge length.

The loads to be employed with these specimens were predetermined by first establishing the area of the gauge length and multiplying this value by the desired prestress level (235,000 psi).

A stress strain record was made for each specimen during the prestressing operations, carefully recording both the load and strain which resulted. The elongation and stress were determined for each specimen from these data. Elongation was further substantiated by metallurgically measuring the extension of the gauge length after each sample was prestressed.

Figure 20 is a typical stress-strain curve, as recorded for Specimen No. 7 showing the load and strain resultant from this prestressing operation.

The physical properties for each specimen tested are shown in Tables XVI through XIX. It may be noted that half of the specimens from each panel were tested at ambient, while the other half were tested at -320°F. A careful analysis of these data indicates that the yield strength varied between 214,000 and 224,000 psi, with an elongation of 10 to 13 percent when tested at ambient. At -320°F the material demonstrated a yield strength of 296,000 to 308,000 psi yield strength, with 10 to 12 percent elongation.

Figure 21 is a typical stress-strain curve for Specimen No. 4, which was tested at ambient, indicating both load and strain. From this record, a yield strength of 0.2 percent offset was determined.

TABLE VIII

PRE-STRESSED 301 STAINLESS

Dwg. No. Spec. No.	Before Thickness	Before Width	Before Area	Load	Elong., %2"	Stress psi	After Thickness	After Width	After Area
SK 10002 N-1									
1	.2230	1.4830	.331	77800	12	235,000	.2120	1.421	.3013
2*	.2160	1.4530	.3138	73800	4.5	235,200	.2110	1.425	.3007
3	.2200	1.4840	.3265	76700	12.0	234,900	.2090	1.420	.2968
4	.2200	1.4860	.3269	76800	13.0	234,900	.2080	1.421	.2956
5	.2210	1.4900	.3293	77400	13.0	235,000	.2100	1.423	.2988
*This bar pre-stressed to 47,700 load lbs. and returned to 0 prior to pre-stressing to 235,000 psi.									
6	.221	1.479	.3269	76800	13.0	234,900	.210	1.413	.2967
7	.222	1.466	.3255	76900	13.5	236,300	.211	1.400	.2954
8	.222	1.471	.3266	76750	12.0	235,000	.211	1.406	.2967
9**	.2140	1.436	.3073	72200	10.0	234,900	.2130	1.435	.3057
10	.2190	1.480	.3241	76200		235,100	Broke while pre-stressing.		

** This bar prestressed to 50,000 load lbs. and returned to 0 prior to prestressing to 235,000 psi.

TABLE IX

PRE-STRESSED 301 STAINLESS

Dwg. No. Spec. No.	Before Thickness	Before Width	Before Area	Load	Elong., %2	Stress, psi	After Thickness	After Width	After Area
SK 10002 N-2									
1	.2220	1.482	.3290	77300	13.0	235,000	.2115	1.412	.2986
2	.2225	1.481	.3295	Void	Spec. failed during prestressing.				
3	.223	1.481	.3303	77600	13.0	234,900	.212	1.411	.2991
4	.2225	1.484	.3302	77600	12.5	235,000	.212	1.412	.2993
5	.222	1.490	.3308	77700	12.5	234,900	.212	1.422	.3015
6	.222	1.486	.3299	77500	12.0	234,900	.212	1.417	.3004
7	.222	1.481	.3288	77300	12.0	235,100	.212	1.416	.3002
8	.222	1.483	.3292	77400	12.0	235,100	.2110	1.416	.2988
9	.222	1.482	.3290	77300	12.0	235,000	.2115	1.414	.2991
10	.222	1.484	.3294	77400	12.0	235,000	.212	1.417	.3004
11	.2220	1.481	.3288	77300	11.5	235,100	.2115	1.414	.2991
12	.2220	1.472	.3268	76800	12.0	235,000	.2110	1.405	.2965

TABLE X

PRE-STRESSED 301 STAINLESS

Dwg. No. Spec. No.	Before Thickness	Width	Area	Load	Elong., %2	Str., Psi	After Thickness	Width	Area
SK 10003 N-1 Weld									
1	.215	1.484	.3191	75000	11.0	235,000	.203	1.423	.2889
2	.2165	1.492	.3230	76000	11.0	235,300	.207	1.431	.2962
3	.2140	1.474	.3154	74100	11.0	234,900	.203	1.411	.2864
4	.2130	1.482	.3157	74200	11.0	235,000	.203	1.419	.2881
5	.217	1.483	.3218	75600	11.0	234,900	.205	1.409	.2888
6	.215	1.483	.3188	75000	11.0	235,300	.205	1.420	.2911
7	.215	1.477	.3176	24200	---	76,200	Spec. failed in weld.		
8	.215	1.487	.3197	75200	11.0	235,200	.204	1.424	.2905
9	.2160	1.480	.3197	75100	11.0	234,900	.205	1.421	.2913
10	.2170	1.480	.3212	75700	11.0	235,700	.206	1.419	.2923

TABLE XI

PRE-STRESSED 301 STAINLESS

Dwg. No.	Before						After		
Spec. No.	Thickness	Width	Area	Load	Elong., %2	Stress, psi	Thickness	Width	Area
SK 10003									
N-2 Weld									
*1	.203	1.490	.3025	58200	9.0	192,400	Spec. failed		
*2	.213	1.486	.3165	74400	10.5	235,100	.202	1.421	.2870
*3	.213	1.488	.3169	74500	11.5	235,100	.203	1.422	.2887
*4	.215	1.486	.3195	66700	10.5	208,800	Spec. failed		
*Weld Beads ground flush before pre-stressing.									
6	.212	1.490	.3159	74200	10.0	234,900	.2040	1.430	.2917
7	.215	1.480	.3182	74800	10.0	235,100	.2035	1.416	.2882
8	.221	1.485	.3282	77100	10.5	234,900	.2100	1.419	.2980
9	.222	1.478	.3281	77100	10.5	235,000	.211	1.414	.2984
10	.214	1.467	.3139	73800	11.0	235,100	.204	1.399	.2854
11	.214	1.484	.3176	74600	11.0	234,900	.204	1.421	.2899
12	.214	1.482	.3171	74500	11.0	234,900	.204	1.417	.2891

TABLE XII

PRE-STRESSED 301 STAINLESS

Dwg. No.		Before						After	
Spec. No.	Thickness	Width	Area	Load	Elong., %2"	Stress psi	Thickness	Width	Area
SK 10004 N-1									
1	.217	1.481	.3214	75500	13.5	234,900	.205	1.417	.2905
2	.218	1.489	.3246	76300	13.5	235,100	.203	1.426	.2895
3	.215	1.478	.3178	74700	13.0	235,100	.202	1.416	.2860
4	.216	1.487	.3211	75500	13.5	235,100	.203	1.423	.2889
5	.214	1.481	.3169	74500	13.0	235,100	.202	1.417	.2862
6	.212	1.483	.3144	73900	12.5	235,100	.202	1.423	.2874
7	.216	1.479	.3195	75100	12.5	235,100	.205	1.415	.2901
8	.215	1.488	.3199	75200	12.5	235,100	.203	1.425	.2893
9	.213	1.480	.3152	74100	13.0	235,100	.201	1.418	.2850
11	.216	1.480	.3197	75100	13.0	234,900	.204	1.418	.2893
12	.214	1.479	.3165	74400	13.0	235,100	.202	1.421	.2870

TABLE XIII

PRE-STRESSED 301 STAINLESS

Dwg. No. Spec. No.	Before Thickness	Before Width	Before Area	Load	Elong., %2"	Stress psi	After Thickness	After Width	After Area
SK 10004 N-2									
1	.222	1.466	.3255	76500	13.5	235,000	.209	1.402	.2930
2	.220	1.483	.3263	76700	13.0	235,100	.207	1.417	.2933
3	.221	1.477	.3264	76700	13.5	235,000	.211	1.407	.2969
4	.221	1.463	.3233	76000	13.0	235,100	.210	1.396	.2932
5	.220	1.497	.3293	77400	12.5	235,000	.210	1.430	.3003
6	.219	1.489	.3261	76600	13.0	234,900	.207	1.420	.2939
7	.220	1.466	.3225	75800	13.5	235,000	.206	1.395	.2874
8	.219	1.514	.3316	78000	13.0	235,200	.208	1.443	.3001
9	.219	1.467	.3212	75500	13.5	235,100	.207	1.394	.2886
10	.220	1.489	.3276	77000	13.0	235,000	.207	1.419	.2937
11	.219	1.277	.2797	65700	13.0	234,900	.206	1.237	.2548
12	.219	1.259	.2757	64800	13.5	234,700	.206	1.200	.2472

TABLE XIV

PRE-STRESS 301 STAINLESS

Dwg. No. Spec. No.	Before Thickness	Before Width	Before Area	Load	Elong., %2	Stress psi	After Thickness	After Width	After Area
K 10005 (Welded)									
N-1									
1	.215	1.477	.3176	74600	12.0	234,900	.204	1.411	.2878
2	.214	1.443	.3088	72600	12.0	235,100	.202	1.380	.2788
3	.217	1.474	.3199	61800	---	193,200	Spec. failed.		
4	.214	1.481	.3169	74500	12.5	235,100	.199	1.418	.2822
5	.216	1.479	.3195	75100	12.5	235,100	.205	1.414	.2899
6	.212	1.443	.3059	71900	13.0	235,000	.200	1.379	.2758
7	.213	1.482	.3157	74200	12.5	235,000	.196	1.417	.2777
8	.214	1.484	.3176	74600	12.5	234,900	.201	1.417	.2848
9	.216	1.476	.3188	74900	12.5	234,900	.202	1.409	.2846
10	.214	1.473	.3152	74100	12.5	235,100	.200	1.409	.2818

TABLE XV

PRE-STRESSED 301 STAINLESS

Dwg. No. Spec. No.	Before Thickness	Width	Area	Load	Elong., %2	Stress psi	After Thickness	Width	Area
SK 10005 N-2 (Welded)									
1	.2220	1.490	.3308	33000	---	99800	Spec. failed.		
2	.225	1.478	.3326	78200	13.0	235100	.216	1.410	.3046
3	.215	1.473	.3167	69900	---	220700	Spec. failed.		
4	.225	1.476	.3321	78000	13.0	234900	.213	1.415	.3014
5	.225	1.471	.3310	77800	13.0	235000	.211	1.406	.2967
6	.220	1.467	.3227	75800	13.0	234900	.207	1.404	.2906
7	.2140	1.475	.3157	74200	12.5	235000	.203	1.408	.2858
8	.2130	1.475	.3142	73800	12.5	234900	.201	1.411	.2836
9	.2200	1.482	.3260	65800	---	201800	Spec. failed.		
10	.222	1.488	.3303	77600	12.5	234900	.210	1.423	.2988

LOAD-STRAIN CURVE - SPECIMEN NO. 7
SKC 10002 N-1
PRESTRESSED AT -320°F.

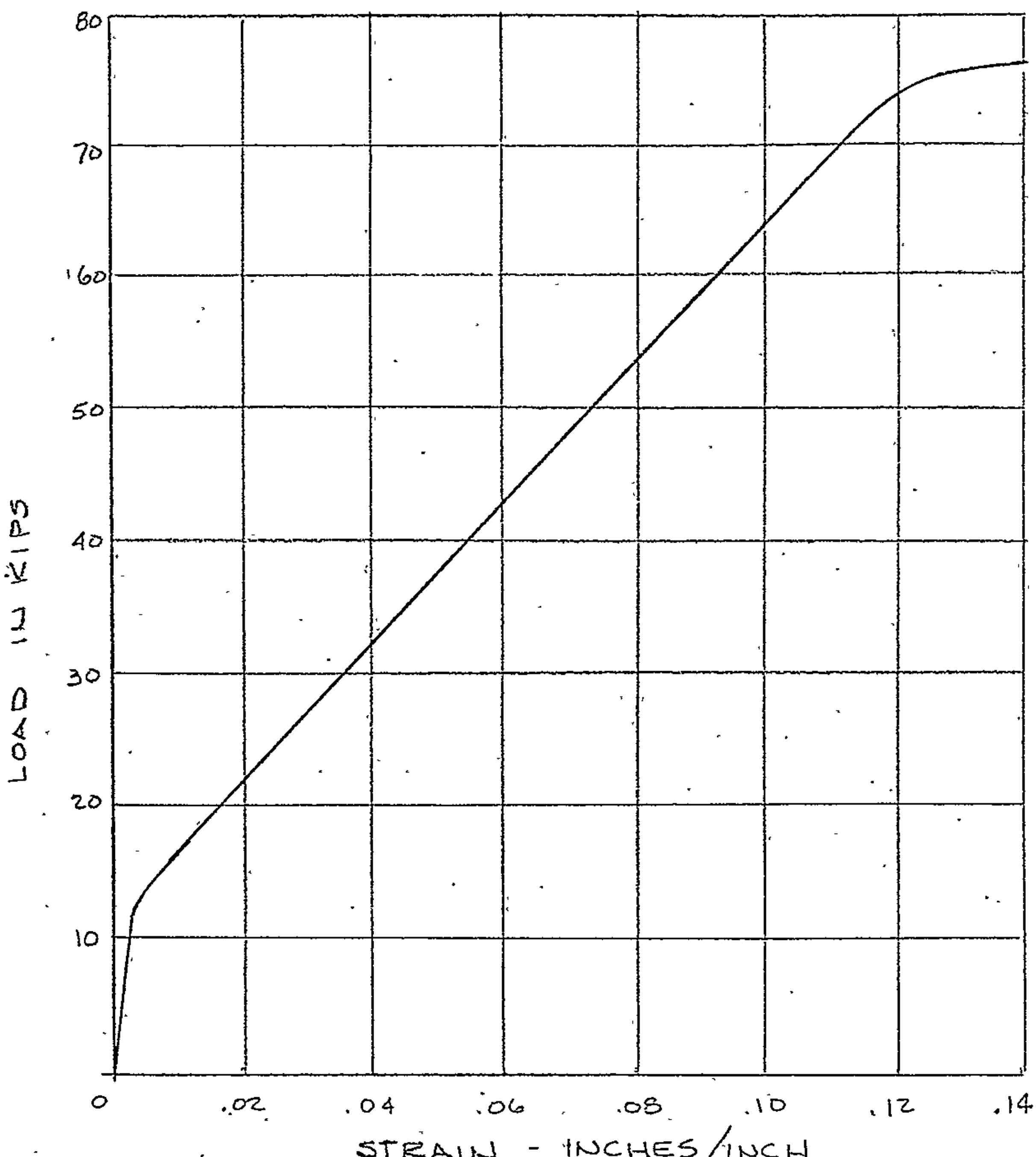


FIGURE 20

TABLE XVI

EVALUATION OF CRYOGENICALLY STRETCH FORMED 301 AUSTENITIC STAINLESS STEEL

Spec. No.	Dimension in Thk.	Dimension in Wdth.	Area Sq.In.	Ult. Ld. lbs.	0.2% Offset Y. Ld. lbs.	Gage Length	Elong. %	Ultimate Stress psi	0.2% Offset Y. Stress psi
SK 10002 N-1		Tested at ambient.							
1	.212	1.421	.3013	68200	67700	2	12.5	226,400	224,700
2*	.2110	1.425	.3007	66200	61700	2	13.5	220,200	205,200
3	.2090	1.420	.2968	67700	66200	2	11.0	228,100	223,000
4	.2080	1.421	.2956	67700	66000	2	12.0	229,000	223,300
5	.2100	1.423	.2980	68500	67000	2	12.0	229,900	224,800
		Tested at -320°F.							
6	.210	1.413	.2967	91200	91000	2	9.0	307,400	306,700
7	.211	1.400	.2954	91000	91000	2	10.5	308,100	308,100
8	.211	1.406	.2967	91200	90800	2	10.5	307,400	306,000
9*	.213	1.435	.3057	89300	81000	2	12.5	292,100	265,000

*These specimens were pre-stressed twice, see pre-stressing data for further information.

TABLE XVII

EVALUATION OF CRYOGENICALLY STRETCH FORMED 301 AUSTENITIC STAINLESS STEEL

Spec. No.	Dimension in Thk.	Wdth.	Area Sq.In.	Ult. Ld. lbs.	0.2% Offset Y. Ld. lbs.	Gage Length	Elong. %	Ultimate Stress psi	0.2% Offset Y. Stress psi
SK 10002 N2	Tested at ambient.								
1	.2115	1.412	.2986	67600	65500	2	12.0	226,400	219,400
3	.212	1.411	.2991	68500	66900	2	12.0	229,000	223,700
4	.212	1.412	.2993	68000	66400	2	12.0	227,200	221,900
5	.212	1.422	.3015	67800	65300	2	10.0	224,900	216,600
6	.212	1.417	.3004	68700	65900	2	11.5	228,700	219,400
	Tested at -320°F.								
7	.212	1.416	.3002	90200	90000	2	11.5	300,500	299,800
8	.211	1.416	.2988	90400	90200	2	10.0	302,500	301,900
9	.2115	1.414	.2991	89900	89900	2	12.0	300,600	300,600
10	.212	1.417	.3004	90300	89600	2	*	300,600	298,300
11	.2115	1.414	.2991	90000	89500	2	7.5	300,900	299,200
12	.2110	1.405	.2965	89400	89000	2	9.0	301,500	300,200

*Piece missing, cannot measure elongation.

TABLE XVIII

EVALUATION OF CRYOGENICALLY STRETCH FORMED 301 AUSTENITIC STAINLESS STEEL

Spec. No.	Dimension in Thk.	Wdth.	Area Sq.In.	Ult. Ld. lbs.	0.2% Offset Y. Ld. lbs.	Gage Length	Elong. %	Ultimate Stress psi	0.2% Offset Y. Stress psi
SK 10003	N-1	Weld	Tested at ambient.						
1	.203	1.423	.2889	66000	63000	2	13.0	228,500	218,100
2	.207	1.431	.2962	66300	63500	2	11.5	223,800	214,400
3	.203	1.411	.2864	65200	62700	2	13.0	227,700	218,900
4	.203	1.419	.2881	64900	62700	2	11.0	225,300	217,600
5	.205	1.409	.2888	66000	63600	2	8.0*	228,500	220,200
			Tested at -320°F.						
6	.205	1.420	.2911	87500	86300	2	11.0	300,600	296,500
8	.204	1.424	.2905	87800	87200	2	11.0	302,200	300,200
9	.205	1.421	.2913	87800	87000	2	10.0	301,400	298,700
10	.206	1.419	.2923	88800	87500	2	BOGL	303,800	299,300

*Spec. Broke near gage mark.

TABLE XIX

EVALUATION OF CRYOGENICALLY STRETCH FORMED 301 AUSTENITIC STAINLESS STEEL

Spec. No.	Dimension in Thk.	Dimension in Wdth.	Area Sq.In.	Ult. Ld. lbs.	0.2% Offset Y. Ld. lbs.	Gage Length	Elong. %	Ultimate Stress psi	0.2% Offset Y. Stress psi
SK10003 N-2 Weld		Tested at ambient.							
2	.202	1.421	.2870	66200	63900	2	11.0	230,700	222,600
3	.302	1.422	.2887	65200	64000	2	11.5	225,800	221,700
6	.204	1.430	.2917	65400	62600	2	11.0	224,200	214,600
7	.2035	1.416	.2882	65900	63300	2	BOGL	228,700	219,600
8	.2100	1.419	.2980	68500	65300	2	12.5	229,900	219,100
		Tested at -320°F.							
9	.211	1.414	.2984	90700	89400	2	BOGL	304,000	299,600
10	.204	1.399	.2854	86700	85900	2	9.5	303,800	301,000
11	.204	1.421	.2899	87500	86000	2	12.0	301,800	296,700
12	.204	1.417	.2891	87400	86300	2	11.0	302,300	298,500

LOAD - STRAIN CURVE - SPECIMEN No. 4
SKC 10002 N-1
AMBIENT FAILURE

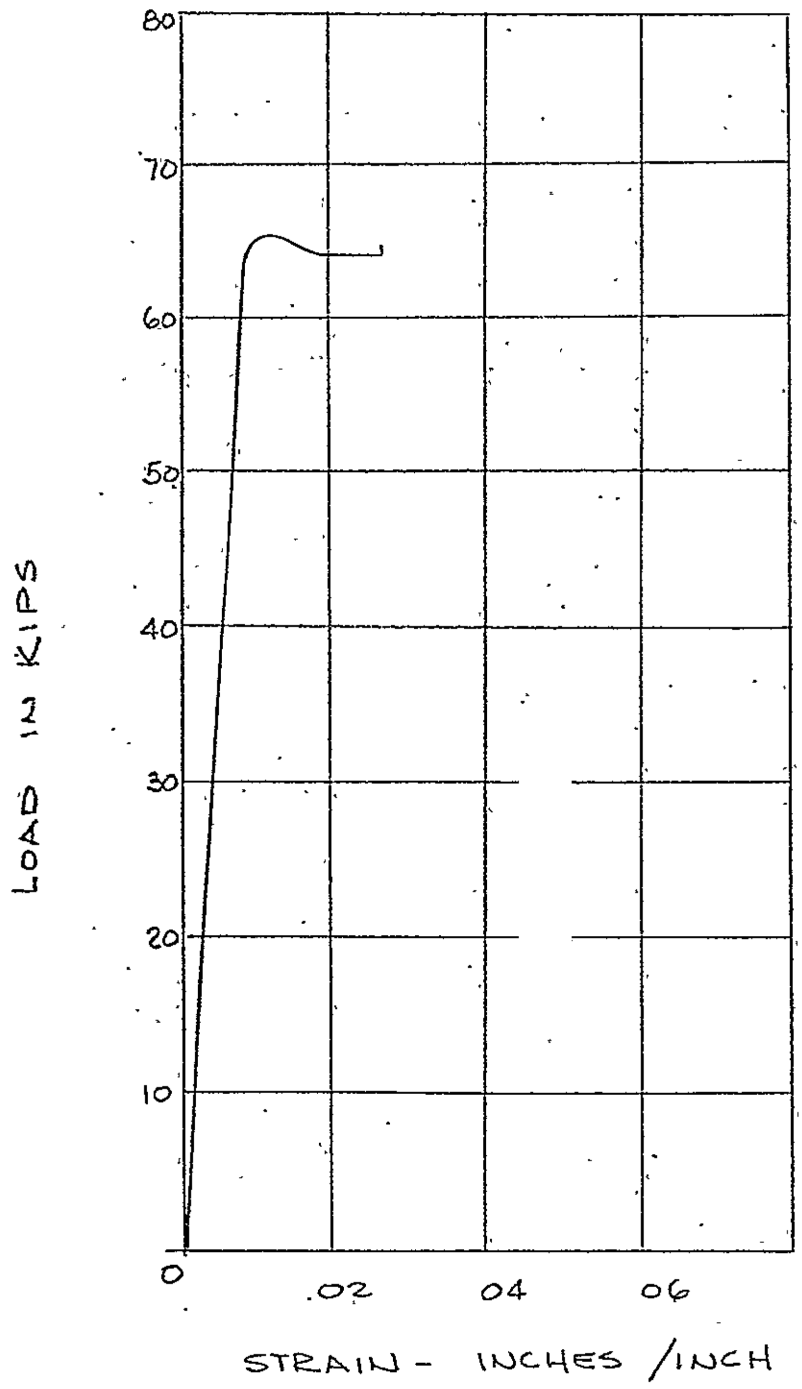


FIGURE 21

Figure 22 illustrates the test set-up and tensile specimens before and after test that were employed to establish the physical properties of the material. The cryostat shown is used to contain liquid nitrogen during the testing operation. The specimen is mounted between the jaws of the tensile testing machine and is enclosed by the insulated cryostat. A cryogenic extensometer with a mechanical take-off may also be seen in the picture.

Tables XX through ~~XXIII~~ define the plain strain fracture toughness values, K_{IC}, for the specimens coming from each panel when tested at both ambient and -320°F. All of these values were determined by using a center notch specimen containing a fatigue crack part way through the specimen. Careful attention was given to the establishment of a fatigue crack of sufficient size such that σ_{nom} was always less than σ_{ys}. Thus, a valid K_{IC} value was obtained on each specimen tested.

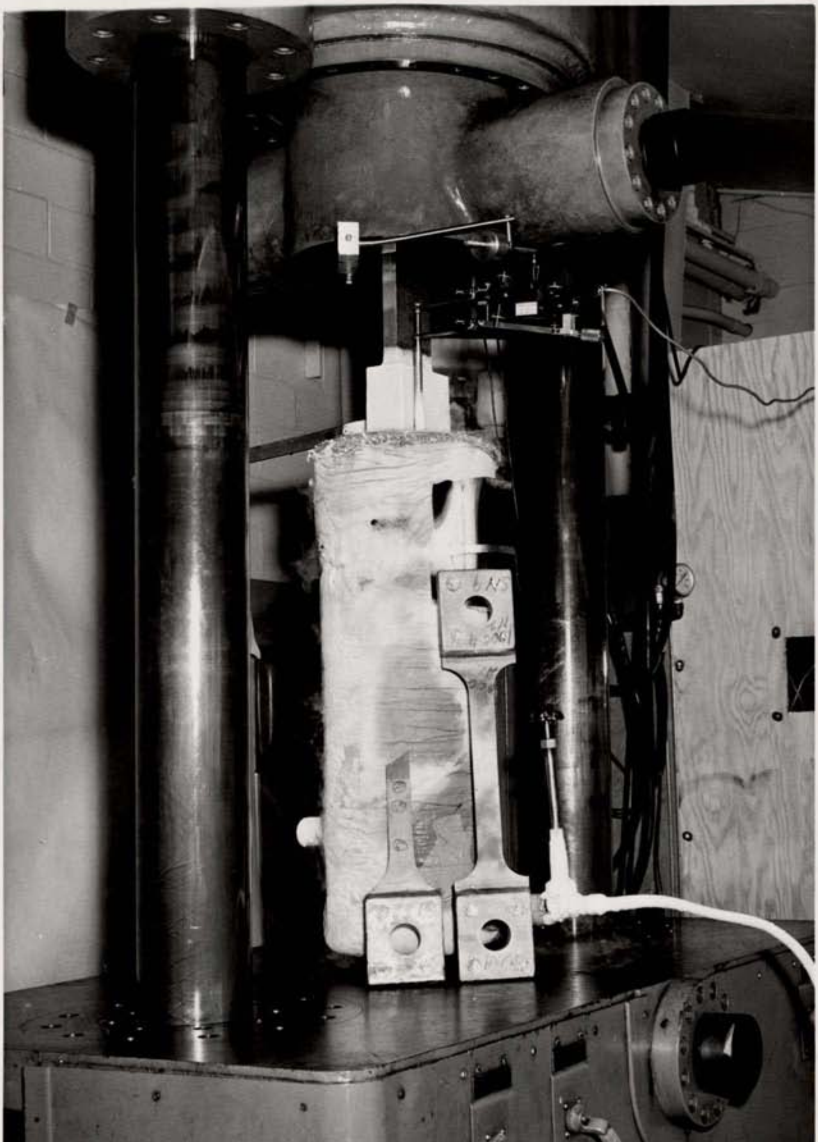
It may be noted that the lowest K_{IC} value for this material, when tested at ambient temperature, was 92.8 Ksi $\sqrt{in.}$, while the highest value was 105 Ksi $\sqrt{in.}$ Attention is directed to the uniformity of these test data.

The K_{IC} values for the material tested at -320°F are much more erratic than those obtained at ambient temperature. These values range from a low of 69.3 Ksi $\sqrt{in.}$ to a high of 104.8 Ksi $\sqrt{in.}$; however, most of the values derived from these tests indicate that the material has a K_{IC} value of approximately 85 Ksi $\sqrt{in.}$ when tested at -320°F. See Figure 23 for notch specimen photographs.

In order to further substantiate the validity of K_{IC} values described above, eight additional tests were carried out at ambient temperature to determine the K_{IC} value by the single edge notch tensile test. This test employs the electrical potential method of determining "pop-in" load. A review of the data contained in Table XXIV

will show excellent agreement obtained between values determined by the SEN method and that obtained from the PTC test method. It may be noted that these test values average approximately 105 Ksi.$\sqrt{in.}$ for the material at ambient temperature.

It should be noted that the weld bead was ground flush with the parent material after prestressing the specimens. This, of course, insured determination of the weld bead properties.



Cryogenic Testing of 301 Stainless Steel at -320°F, Using Liquid Nitrogen.

FIG. 22

TABLE XX

PARTIAL THICKNESS (K_{Ic}) TEST SPECIMENS

CRYOGENIC PRE-STRESSED 301 STAINLESS

SKC 10004N-1 (Non Welded)

Spec. No.	Crack Half Lgth. (a)	Crack Dpth. (b)	b/a	σ_{nom}	$\frac{\sigma_{nom}}{\sigma_{ys}}$	$\frac{\sigma^2}{\sigma_{ys}^2}$	$0.212\frac{\sigma^2}{\sigma_{ys}^2}$	ϕ^2	$\phi^2 - 0.212\frac{\sigma^2}{\sigma_{ys}^2}$	$3.77\sigma^2 b$	$\frac{3.77\sigma^2 b}{\phi^2 - 0.212\frac{\sigma^2}{\sigma_{ys}^2}}$	K_{Ic}
SK-10004	N-1											
1	0.152	0.100	0.658	213,100	0.951	0.905	0.192	1.73	1.538	171.2×10^8	111.3×10^8	105.5
2	0.143	0.085	0.594	214,500	0.958	0.917	0.194	1.625	1.431	147.4×10^8	103.0×10^8	101.5
3	0.148	0.091	0.615	217,100	0.969	0.939	0.199	1.66	1.461	161.7×10^8	110.7×10^8	105.1
4	0.130	0.078	0.600	217,000	0.969	0.938	0.199	1.63	1.431	138.5×10^8	96.8×10^8	98.4
5	0.129	0.076	0.589	207,200	0.925	0.856	0.181	1.61	1.429	123.0×10^8	86.1×10^8	92.8
Tested at ambient.												
6	Bad crack.			191,700	0.625	0.390	0.083					
7	Bad crack.			194,800	0.635	0.403	0.085					
8	0.141	0.093	0.660	186,300	0.607	0.368	0.078	1.735	1.667	121.69×10^8	73.0×10^8	85.4
9	0.141	0.091	0.645	193,300	0.630	0.397	0.084	1.715	1.631	128.2×10^8	78.6×10^8	88.7
11	0.148	0.091	0.615	180,400	0.588	0.346	0.073	1.660	1.587	111.6×10^8	70.4×10^8	83.9
12	0.142	0.083	0.585	211,500	0.689	0.475	0.101	1.600	1.499	140.0×10^8	93.4×10^8	96.6

Tested at -320°F.

TABLE XXI

PARTIAL THICKNESS (K_{Ic}) TEST SPECIMENS

CRYOGENIC PRE-STRESSED 301 STAINLESS

SKC 10004 N-2 (Non-Welded)

Spec. No.	Crack Half Lgth. (A)	Crack Dpth. (B)	b/a	σ_{nom}	σ_{nom}/σ_{ys}	σ^2/σ_{ys}^2	$0.212\,\sigma^2/\sigma_{ys}^2$	ϕ^2	$\phi^2 - 0.212\,\sigma^2/\sigma_{ys}^2$	$3.77\,\sigma^2 b$	$\frac{3.77\,\sigma^2 b}{\phi^2 - 0.212\,\sigma^2/\sigma_{ys}^2}$	K_{Ic}
SK-10004 N-2												
1	0.296	0.148	---	166,200	0.755	0.570	0.121	Bad crack.				
2	0.150	0.089	0.593	213,100	0.968	0.937	0.199	1.62	1.421	152.4×10^8	107.2×10^8	103.5
3	0.167	0.105	0.629	199,400	0.906	0.820	0.174	1.68	1.506	157.4×10^8	104.5×10^8	102.3
4	0.134	0.092	0.687	217,300	0.987	0.974	0.206	1.79	1.584	164.0×10^8	103.5×10^8	101.8
8	0.169	0.095	0.562	202,600	0.92	0.847	0.180	1.57	1.39	147.0×10^8	105.7×10^8	102.8
Tested at ambient.												
6	0.183	0.098	0.536	142,900	0.476	0.227	0.0481	1.525	1.477	75.4×10^8	51.04×10^8	71.4
9	0.145	0.082	0.566	193,000	0.643	0.414	0.088	1.57	1.482	115.2×10^8	77.7×10^8	88.1
10	0.162	0.078	0.481	186,200	0.621	0.385	0.082	1.44	1.358	102.0×10^8	75.1×10^8	86.7
11	0.173	0.102	0.590	140,100	0.467	0.218	0.046	1.62	1.574	75.5×10^8	48.0×10^8	69.3
12	0.157	0.084	0.535	171,900	0.573	0.328	0.070	1.525	1.455	93.6×10^8	64.3×10^8	80.2

Tested at $-320^{\circ}F$.

TABLE XXII

PARTIAL THICKNESS (K_{Ic}) TEST SPECIMENS

CRYOGENIC PRE-STRESSED 301 STAINLESS

SKC 10005 N-1 (Welded)

Spec. No.	CRACK HALF LGTH. (A)	CRACK DEPTH (B)	b/a	σ nom	$\frac{\sigma_{nom}}{\sigma_{ys}}$	$\frac{\sigma^2}{\sigma_{ys}^2}$	$0.212\frac{\sigma^2}{\sigma_{ys}^2}$	ϕ^2	$\phi^2\ 0.212\frac{\sigma^2}{\sigma_{ys}^2}$	$3.77\,\sigma^2 b$	$\frac{3.77\,\sigma^2 b}{\phi^2\ 0.212\frac{\sigma^2}{\sigma_{ys}^2}}$	K_{Ic}
SK	10005	N-1.										
1	0.153	0.077	0.503	206.7	0.949	0.901	0.191	1.470	1.279	124.0×10^8	96.9×10^8	98.4
4	0.137	0.069	0.504	225.9	1.037	1.076	0.228	1.470	1.242	132.7×10^8	106.8×10^8	103.3
5	0.145	0.076	0.524	216.9	0.996	0.992	0.210	1.505	1.295	134.8×10^8	104.1×10^8	102.0
6	0.150	0.089	0.593	216.6	0.994	0.989	0.210	1.620	1.410	157.4×10^8	111.6×10^8	105.6
Tested at ambient.												
7	0.137	0.062	0.453	199.6	0.668	0.446	0.095	1.40	1.305	93.1×10^8	71.3×10^8	84.4
8	0.138	0.079	0.572	166.6	0.558	0.311	0.066	1.58	1.514	82.7×10^8	54.6×10^8	73.9
9	0.134	0.083	0.619	199.4	0.668	0.446	0.095	1.66	1.565	124.4×10^8	79.5×10^8	89.2
10	0.142	0.072	0.507	196.2	0.657	0.432	0.092	1.47	1.378	104.5×10^8	75.8×10^8	87.1
Tested @ -320°F.												

TABLE XXIII

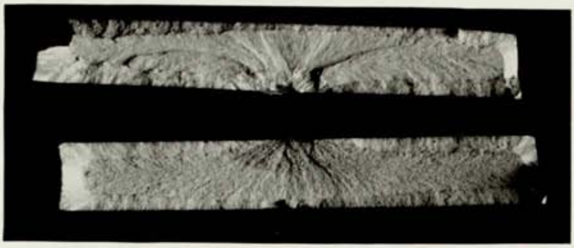
PARTIAL THICKNESS (K_{Ic}) TEST SPECIMENS

CRYOGENIC PRE-STRESSED 301 STAINLESS

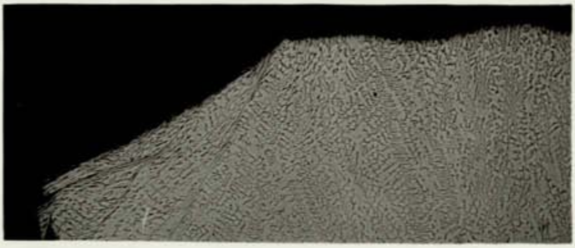
SK 10005 N-2 (Welded)

Spec. No.	CRACK HALF LGTH. (A)	CRACK DPTH. (B)	b/a	σ_{nom}	$\frac{\sigma_{nom}}{\sigma_{ys}}$	$\frac{\sigma^2}{\sigma_{ys}^2}$	$\frac{.212\sigma^2}{\sigma_{ys}^2}$	ϕ^2	$\phi^2 - \frac{.212\sigma^2}{\sigma_{ys}^2}$	$3.77\sigma^2 b$	$\frac{3.77\sigma^2 b}{\phi^2 - .212\sigma^2/\sigma_{ys}^2}$	K_{Ic}
7	0.192	0.080	0.42	213.1	0.971	0.943	0.200	1.35	1.15	137.0×10^8	119.1×10^8	109.1
8	0.145	0.079	0.545	219.8	1.001	1.002	0.212	1.54	1.328	143.9×10^8	108.4×10^8	104.1
10	0.145	0.082	0.566	214.2	0.976	0.953	0.207	1.58	1.373	141.8×10^8	103.3×10^8	101.6
Tested at ambient.												
2	0.160	0.070	0.44	228.8	0.765	0.585	0.124	1.38	1.256	138.0×10^8	109.9×10^8	104.8
4	0.158	0.085	0.54	205.6	0.688	0.473	0.100	1.53	1.43	135.5×10^8	94.8×10^8	97.4
5	0.141	0.070	0.50	176.2	0.589	0.347	0.074	1.47	1.396	81.9×10^8	58.7×10^8	76.6
6	0.144	0.076	0.53	179.8	0.601	0.361	0.077	1.52	1.443	92.6×10^8	64.2×10^8	80.1
Tested at -320°F.												

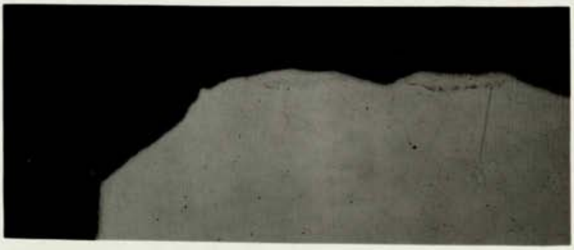
MATERIALS EVALUATION



Notch Specimens
(Upper-welded; Lower-parent metal)



Welded Notch Specimen
Grain Structure - 100X
(fracture edge up)



Parent Metal Notch Specimen
Grain Structure - 100X
(fracture edge up)

FIG. 23

TABLE XXIV

SINGLE EDGE NOTCH K_{Ic} TENSION TEST

301 Stainless Steel

SK 10002 N-1

Spec. No.	a_o	P	B	W	$\frac{a_o}{W}$	$\left(\frac{P}{B}\right)^2 \left(\frac{1}{W}\right)$	$F\left(\frac{a}{W}\right)$	$E\,G_{Ic}$	$\frac{a}{W}$	$F\left(\frac{a}{W}\right)$	$E\,G_{Ic}$	$\frac{\sigma_{nom}}{\sigma_{ys}}$	K_{Ic}
1	.350	5200	.1090	.9910	.353	23.0×10^8	3.84	88.3×10^8	.362	4.06	93.4×10^8		101.3
2	.370	5225	.1070	.995	.372	24.0×10^8	4.38	105.1×10^8	.383	4.74	113.8×10^8		111.8
3	.360	6900	.1360	.995	.362	25.9×10^8	4.06	105.2×10^8	.373	4.4	114.0×10^8		111.9
4	.340	6175	.1140	.995	.342	29.5×10^8	3.54	104.4×10^8	.352	3.8	112.1×10^8		111.0
6	.340	5500	.1080	.996	.341	26.0×10^8	3.50	91.0×10^8	.351	3.78	98.3×10^8		104.0
7	.345	6000	.1230	.997	.346	23.9×10^8	3.64	87.0×10^8	.355	3.90	93.2×10^8		101.2
8	.370	6000	.1290	.996	.371	21.7×10^8	4.37	94.8×10^8	.382	4.72	102.4×10^8		106.1

2. Stress Corrosion Testing

Eight tensile specimens were prepared from heat 8606B rolled plate stock for stress corrosion testing. They were of the bent beam type, and were cut from the plate material in the direction of rolling. For convenience, the material thickness was reduced by machining from one side only. This permitted the examination of any surface effects on the stress corrosion resistance of the material. One-half of the specimens were machined from one side of the plate, and the other four from the other side, so that both surfaces could be evaluated. A series of tests evaluating the stress corrosion resistance of cryogenically stressed 301 has been performed by the Mellon Institute and is reported in their report, "C. J. Owen, STRESS CORROSION OF HIGH STRENGTH STEELS AND ALLOYS", dated December of 1962.

Inasmuch as the work performed by the Mellon Institute indicates that the only anion to which stress corrosion susceptibility is shown is chloride, the corrosion medium employed was sodium chloride solution.

A .75 normal salt solution was employed to approximate sea water conditions. Since the molecular weight of sodium chloride is 58, the .75 normal solution may be converted as follows:

$$\frac{.75 \times 58 \text{ gms NaCl}}{1000 \text{ gms solution}} = \frac{43.5}{1000} =$$

4.35% salt solution

After machining operxtions were completed the specimens were cleaned in accordance with Arde Engineering Specification AES 253, pickled per AES 251 and passivated per AES 254 to simulate the treatments to which vessels would be subjected in actual fabrication.

All specimens were cryogenically prestrained to a true stress of 255 KSI (nominal stress of 233 KSI).

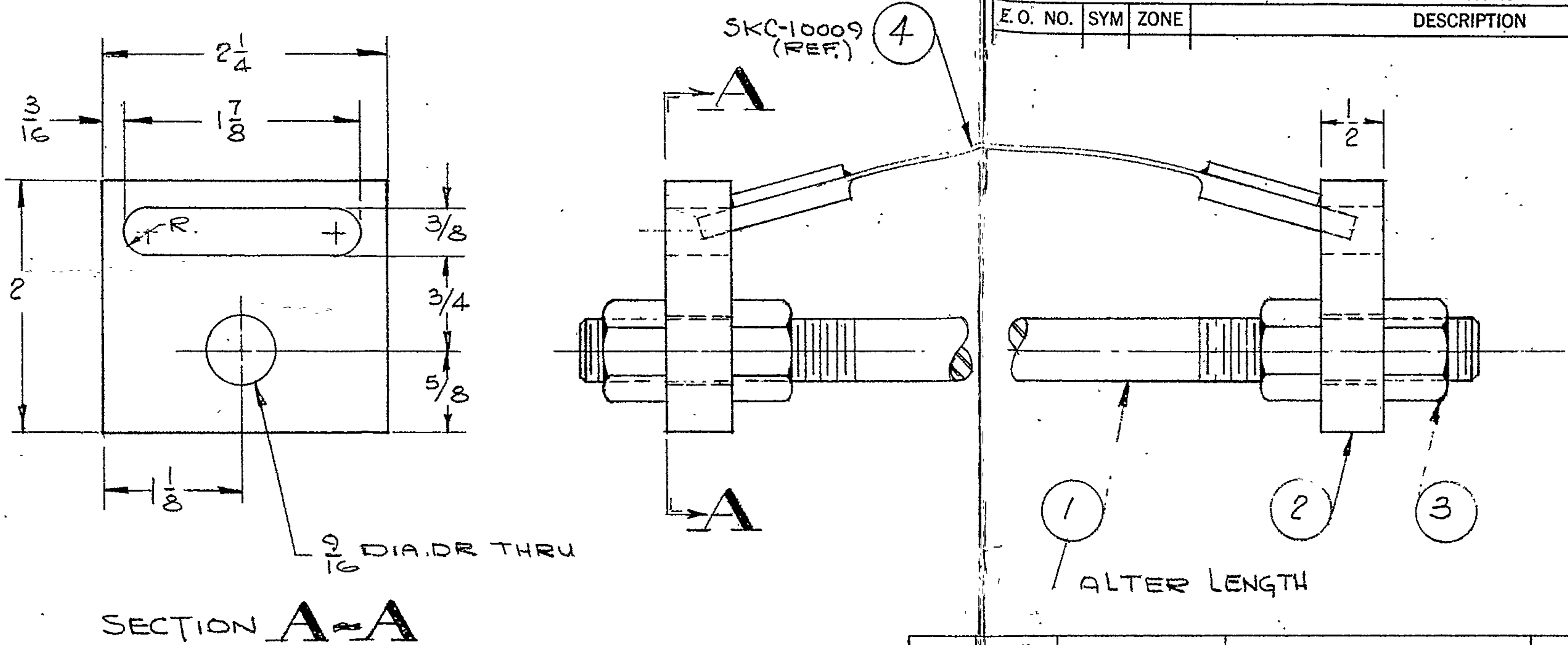
Each specimen then was loaded in a fixture to a strain of 7600 micro-inches/inch, or a stress of 184 KSI (Nominal). See Figure 24. On March 25, 1966 each specimen was loaded in the fixture, and placed in the salt solution. These specimens were removed on August 3, 1966. Air was bubbled through the solution during the entire duration of the test. Solution normality was checked and maintained weekly. See Figure 25.

Upon removal from the salt solution, all specimens were dye penetrant inspected. No dye check indications were found. One of these specimens was microsectioned. No indication of stress corrosion was found.

One specimen was pulled to a cryogenic failure at a nominal stress of 300 KSI. Another specimen was pulled to a nominal room temperature failure stress of 228 KSI. Previous data taken for this heat of material indicates that specimens which had been subjected to a true cryogenic stress of 255 KSI should exhibit a nominal cryogenic failure stress of 287 KSI, and a nominal room temperature failure stress of 218 KSI. The increased strength exhibited by the corrosion test specimens is undoubtedly due to normal room temperature aging effects exhibited on other heats of material previously tested.

The Ardeform tensile specimens used for this corrosion test program were not affected, in any way, by the salt water solution. No evidence of stress corrosion cracking in .75 normal Na. Cl. solution was evident in Ardeform 301 material stressed to a level of 85% of yield over a period of 127 days.

REVISIONS					
E.O. NO.	SYM	ZONE	DESCRIPTION	DATE	APPROVED



				3	4		HEX NUT	PURCH ST'L STEEL	MARINE HARDWARE #1/2-13 TH'D
				2	2		BODY	ST' ST'L TYPE #304	1/2 x 2 x 2 1/4
				1	1		THREADED ROD	PURCH ST'L STEEL	MARINE HARDWARE # 1/2-13 x 12" LG
QTY REQD PER DASH NO.				ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
.X = ±.030, .XX = ±.010, .XXX = ±.005
ANGULAR ±30' FRACTIONS ±1/64
BREAK SHARP EDGES .003-.015
ALL SMALL FILLETS .020-.040R
THREADS PER FED. HNDBK H-28 AND SUPPLEMENTS
DIMENSIONING PER MIL-STD-8
WELD SYMBOLS PER JAN-STD-19
SURFACE ROUGHNESS SYMBOLS PER MIL-STD-10
ALL FINISHED SURFACES 125 √

NEXT ASSEMBLY

DRAWN BY	Hekman	11-8-65
CHECKER		
STRESS ENG'R		
AERO THERMO		
DES. ENG'R	[illegible]	11/8/65
PROJ. ENG'R	[illegible]	11-8-65

ARDÉ, INC.
PARAMUS, N. J.

TITLE
TEST FIXTURE
BENT BEAM

CODE IDENT NO.	SIZE	
05980	B	B-3501
SCALE FULL		SHEET 1 OF 1

B-3501

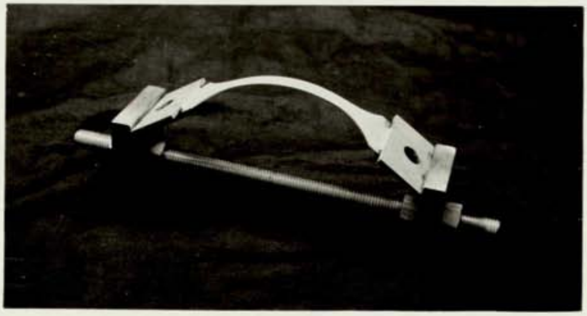
DEFIANCE NO. 107XH

72-A

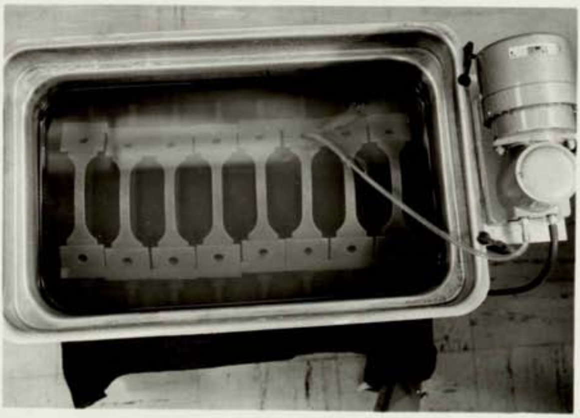
72-B

-72-C

FIGURE 24



Stress Corrosion Specimen
in Stressed Condition



Stress Corrosion Test Setup

FIG. 25

D. Investigation of Spin-Over Process

It was the intent that this phase of the program demonstrate the feasibility of partially closing, or spinning-over the ends of a seamless cylinder to permit the eventual incorporation of machined bosses by welding. It was anticipated that a follow-on of this development effort, at a later date, would result in the successful demonstration of a completely integral, seamless pressure bottle. It was recognized that this later feature is highly desirable; however, was not a part of the scope of the subject program.

Several processing techniques were investigated as a means of spinning-over the ends of seamless cylinders. The majority of the techniques required a seamless cylinder with a wall thickness many times greater than that contemplated in this program. After careful evaluation it appeared that a hot-spinning technique provided the most promising approach. This process is presently applied to the high production fabrication of gaseous and liquid cylindrical storage vessels meeting the very rigid ICC and ASME standards.

The process of hot-spinning consists of preheating a cylindrical section or tube. The cylinder is then clamped in a "collet-type" chuck on a hydraulically operated spinning machine. A hydraulic actuated tool is forced against the end of the spinning cylinder. Gas heaters are used during the spinning process to maintain part temperature.

This phase of the program utilized SA 53 Grade B carbon steel tubing 10.75 inch O.D. by .250 inch wall for development. This represented the closest available size to the requirement of 11.40 inches O D. by .220 inch wall for the final stainless steel version. This investigation showed feasibility of the process and demonstrated repeatability in this heretofore untried diameter.

The hot spinning investigation was carried on at the Marison Company, Elgin, Illinois, with both Arde-Portland and NASA - MSFC personnel present.

Marison was able to easily produce a spun over head with a five (5) inch opening per the detail drawing supplied to them. It was then arranged to have them spin over the ends to a point where material thickness would begin to increase appreciably. This occurred at about a two and one half (2 1/2) inch opening. The next version produced was a fully closed round end. All heads were removed from the cylinders, sectioned, and shipped to Arde for evaluation.

Marison also supplied a section from a fully closed end with an integral external boss for evaluation. This shape had been produced with .250 inch wall SAE 4130 tubing.

In the course of this work, it became apparent that some tooling costs might be eliminated if the length of the integral bottle could be increased in the range of six to ten inches. The spinning machine to be used for this program would have required holding devices between the chuck and the forming tool. However, increasing the cylinder length would enable Marison to use existing tooling. Inasmuch as there was no requirement to hold both the roll and weld version, and the integral head version to the same length, Marison was asked to supply an exact length dimension for tubing to be supplied to them. The Parsons Corp., Traverse City, Michigan, suppliers of the floturned cylinders, were then asked to furnish an anticipated maximum length dimension in order to resolve this change.

Micro and macro evaluations were made on the closures spun by Marison. As may be seen in Figure 26, there is virtually no structural difference between closures spun to different extents. As expected, the carbon steel is not too clean, but no flaws are in evidence. Figure 27 is an indication of 4130 steel taken adjacent

to the boss area on the head that had an integral boss spun in place. On the basis of the samples submitted by Marison, an optimum boss to head juncture diameter of 5 1/2 inches was selected. This represents a 50% closure by hot spinning.

END SPINNING INVESTIGATION

Carbon Steel
50% Closure
50X

Carbon Steel
75% Closure
50X

FIG. 26

END SPINNING INVESTIGATION

SAE 4130 STEEL

CLOSURE WITH INTEGRAL BOSS

FIG. 27

E. Vessel Design

1. General

Vessel design for this program was predicated on demonstrating the feasibility of producing full scale helium bottles for use in the lox tanks of Saturn S-1C. Therefore, the subscale bottles produced must reflect the operational and test pressures consistent with full scale conditions and in accordance with NASA Drawing 20MO2008.

The design considerations to be met were:

1) 10" minimum inside diameter.
2) Thickness ratio full scale to subscale of 1 (.220 nominal thickness).
3) A length to diameter ratio in the range of 3 to 5.
4) Operational and test pressures to correspond with the following full scale pressures:

Working pressure	3000 psi at -320°F
Proof pressure	4500 psi at -320°F
Burst pressure	6660 psi at -320°F

In addition, two distinct designs were to be produced to fulfill design considerations. The fabrication methods were:

1. Welded vessel, with a minimum of 3 girth welds, joining rolled and longitudinally welded cylinders and hydroformed heads. See Figure 28.
2. Integral seamless floturned cylinder with spun-over heads. See Figure 29.

The design of the optimum Ardeformed full scale vessel, described in Figure 30 was established by utilizing the strength level supported by past data, combining same with consideration of fabricability, and providing for minimum weight and envelope requirements. The outside diameter was reduced while maintaining a minimum volume of 31.0 cu.ft.

A uniaxial strength level of 285,000 psi at -320°F was utilized as a basis for determining wall thicknesses. It was felt that this

WELDED PRESSURE VESSEL

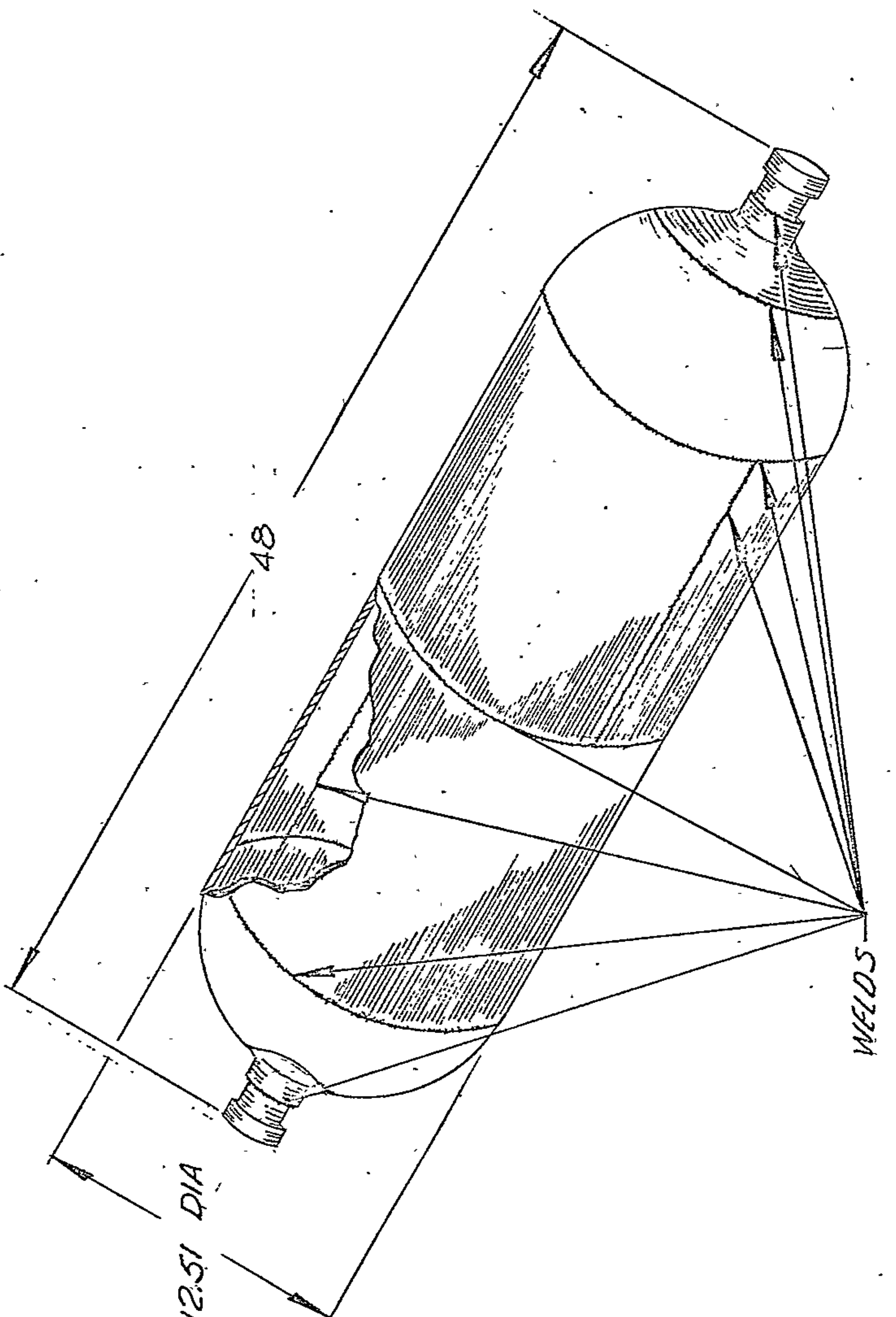


FIGURE 28

INTEGRAL HEAD VESSEL

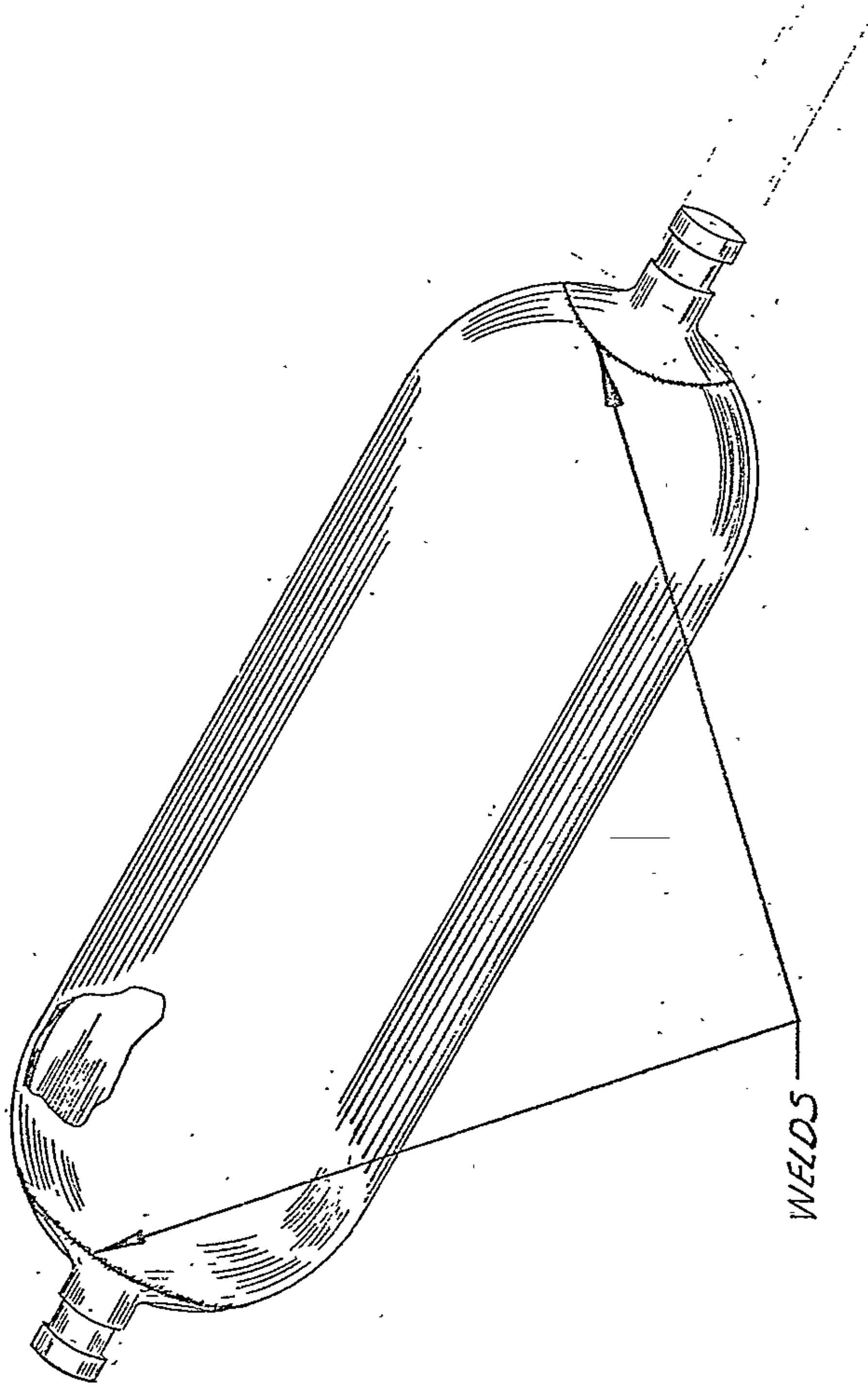
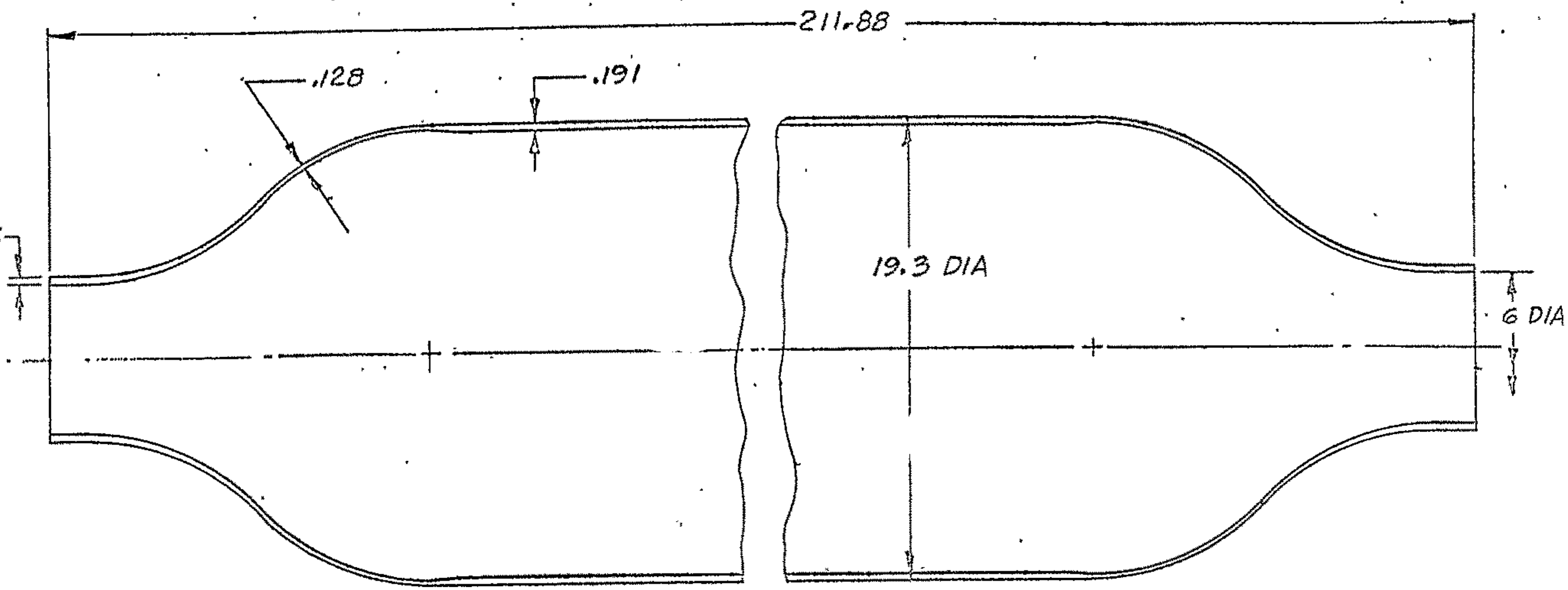


FIGURE 29



ESTIMATED

WEIGHT : 700 LBS MAX.
VOLUME: 31 CU. FT.

ARDE-PORTLAND, INC. PARAMUS, NEW JERSEY SOUTH PORTLAND, MAINE		
TITLE OPTIMUM DESIGN HELIUM STORAGE BOTTLE		
CODE IDENT NO. 12218	SIZE B	SKB1711
SCALE NONE		SHEET

FIGURE 30

stress level was a conservative figure supported by considerable test data. The application of the uniaxial strength to a biaxial condition, as exists in the cylindrical shell of the pressure chamber, permits us to apply a factor of 1.15 or 330,000 psi hoop strength.

Considering the cylinder as a simple pressure vessel, the following stress determination formula was utilized:

$$\sigma = \frac{PR}{t}$$

where:

σ	=	ultimate biaxial strength level	(330,000 psi)
P	=	burst pressure	(6,660 psi)
R	=	inside radius of cylinder	(9.45 inches)

It was then determined that the final wall thickness must be a minimum of .191 inches.

The end extremities were designed to take advantage of lower stress loads in the hemispherical head section. The loading of hemispherical sections is established by the following equation:

$$\sigma = \frac{PR}{2t}$$

Theoretically, in a constant wall thickness vessel the stresses in the head section are one-half that of the cylindrical section. It is, therefore, theoretically possible to reduce the head thickness to one-half that of the cylindrical section. A conservative approach, considering the incorporation of the boss, results in a head wall thickness of two-thirds the cylindrical wall thickness.

Therefore, assuming a cylindrical wall thickness of .191" minimum, a preform wall of .220" would be required when considering wall thickness tolerances and the reduction through cryogenic straining.

The final subscale design, in addition to reflecting full scale operational pressures, had to be sized considering other factors. They were:

1. Use of available tooling where possible.
2. Actual material thickness.
3. Actual material strength.
4. Actual material strain response.

2. Preliminary Subscale Design

Preliminary subscale design layouts were produced and detail drawings released. These were based on data from the testing of similar material and the utilization of existing hydroform tooling.

Preform dimensions:

.220" wall (based on full scale vessel)

10.8 I.D. (based on available tooling)

Final or Postform dimensions:

.191" minimum wall

12.50 I.D.

(both based on a 13% strain at -320°F)

Assuming the subscale vessel would have the same wall thickness and same design stress level, the operating pressure would then change by the ratio

$$\frac{\text{full scale I.D.}}{\text{subscale I.D.}} \text{ or } \frac{18.9}{12.5} = 1.5$$

Subscale pressures would then be:

operating	4500 psi
proof	6750 psi (1.5 x operating)
burst	9,900 psi (2.2 x operating)

3. <u>Final Subscale Design - General</u>

On the basis of the materials evaluation test results, outlined in IV A, it was determined that heat 8606B was a "stiffer" heat than anticipated, and a 13% strain would be excessive. A nominal 10% strain was found to be optimum for this particular heat. Furthermore, incoming inspection showed that the average sheet thickness was .216 inches. Uniaxisl failure values at -320°F indicated a probable ultimate strength in the cylinder of 310-330,000 psi.

The use of existing tooling for hydroformed heads that was available in New Jersey represented enough of a cost saving to justify a change in preform inside diameter to 10.96 inches. These changes would then result in the following postform dimensions:

.195" wall
12.124" inside diameter

The scaling factor between full scale and subscale pressure would then change to $\frac{18.9 \text{ (full scale I.D.)}}{12.12 \text{ (subscale I.D.)}} = 1.56$

Hence, the operating and test pressures would be as follows for the subscale units:

operating pressure:	4680 psi at -320°F
proof pressure:	7020 psi at -320°F
burst pressure:	10,296 psi at -320°F

a) <u>Welded Vessel Design</u>

As may be seen in Figure 28 this version of the pressure vessel was designed to exhibit the weld strength characteristics of an Ardeform vessel, in a configuration similar to a full scale helium bottle. In particular, full scale vessel welding was simulated. Inasmuch as the length of a full scale vessel precludes the use of a single sheet of stock, the subscale vessel was designed to use two short (18") cylinders, rolled and longitudinally welded, and then joined with a girth weld to form a single cylinder. The

longitudinal welds were offset 180° apart. The vessel, when finished with hydroformed heads, would then contain three (3) full diameter girth welds. In addition, boss to head welds and welds within the boss would be utilized. The design required standard operations, such as rolling, hydroforming, welding and machining, that are common to Ardeform pressure vessels produced previously.

b. <u>Integral Vessel Design</u>

The integral head vessel was designed with the same parameters as the roll and weld vessel. However, in this version, as shown in Figure 29, a forging was floturned into a seamless cylinder, which then had its ends hot spun over to achieve a 50% closure. After machining the heads to a consistent wall thickness (.145") bosses were to be welded in place.

V PHASE II - MANUFACTURE OF SUBSCALE VESSELS

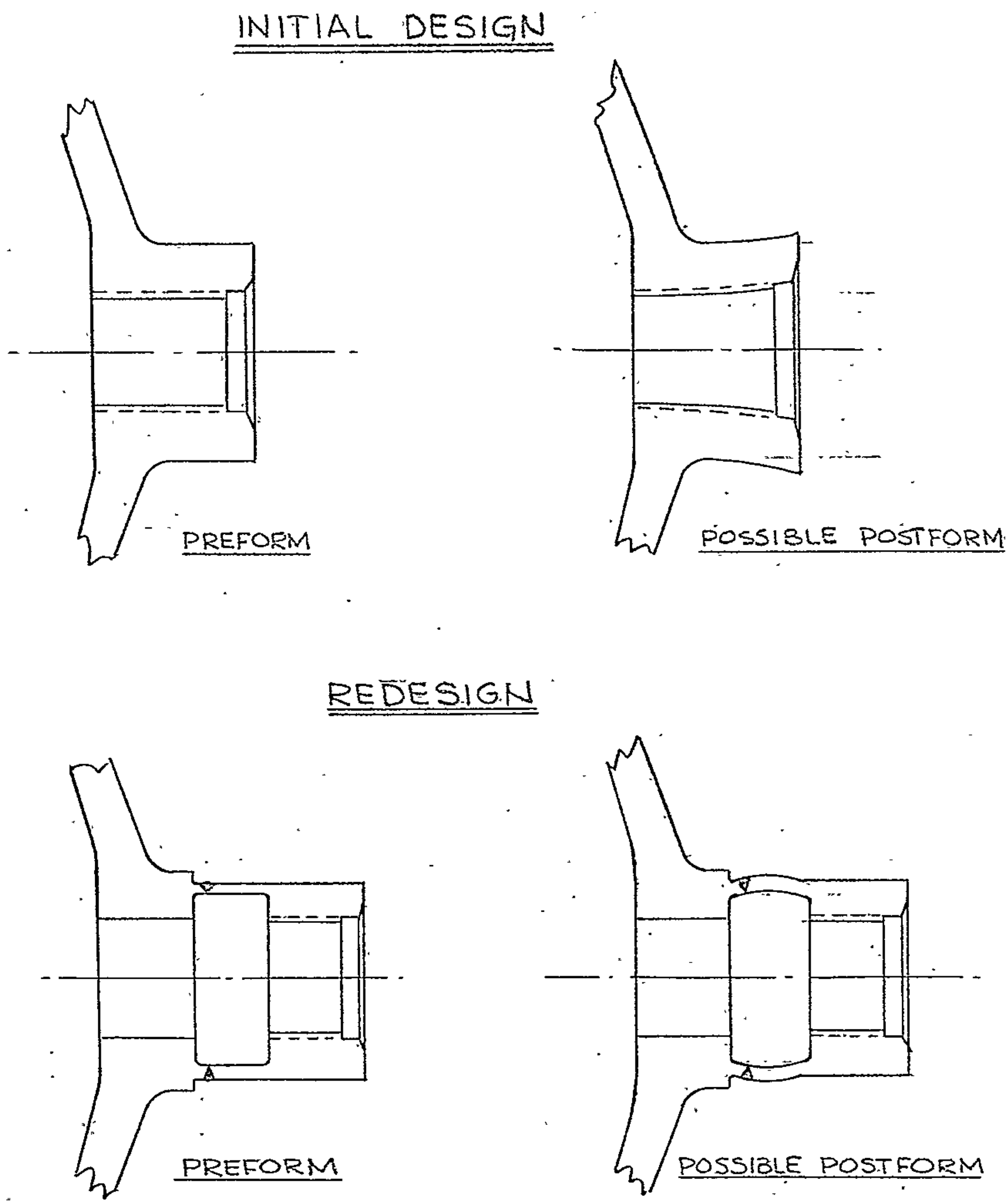
A. Welded Vessel

Plate stock was sheared to blank size and sent to the hydroform vendor (C.B. Kaupp) for head end fabrication. Considerable experience has been accumulated in the fabrication of details of this nature for cryogenically prestrained vessels. The hydroforming process is a relatively inexpensive and reliable means of converting sheet or plate stock to simple curved surfaces. The process requires a male mandrel over which the material is formed. The forming is accomplished by applying a hydraulic force behind a thick rubber pad, thus forcing the material over the male die. Close dimensional control is achieved. Some ten percent thickness variation can be anticipated as a result of the process application.

The .216 thick material was hydroformed into hemispherical heads, and machined on the outside surface to .145 inch thickness all over. Holes were machined to receive the bosses. After machining the heads were cleaned, annealed, pickled and passivated at Arde.

One and one-quarter inch thick sheet bar stainless steel was cut into five inch squares and sent to Tracer Tool Co. for boss fabrication. After manufacture, the bosses were cleaned and radiographically inspected.

Meanwhile, additional analysis was performed on the boss design, since some problems had been encountered on similar vessels. The analysis showed that the part threads themselves might stretch. Therefore, a "stretchable" neck was placed between the part and the boss proper. (See Figure 31) This controlled the location of any possible distortion.



BOSS ANALYSIS

FIGURE 31

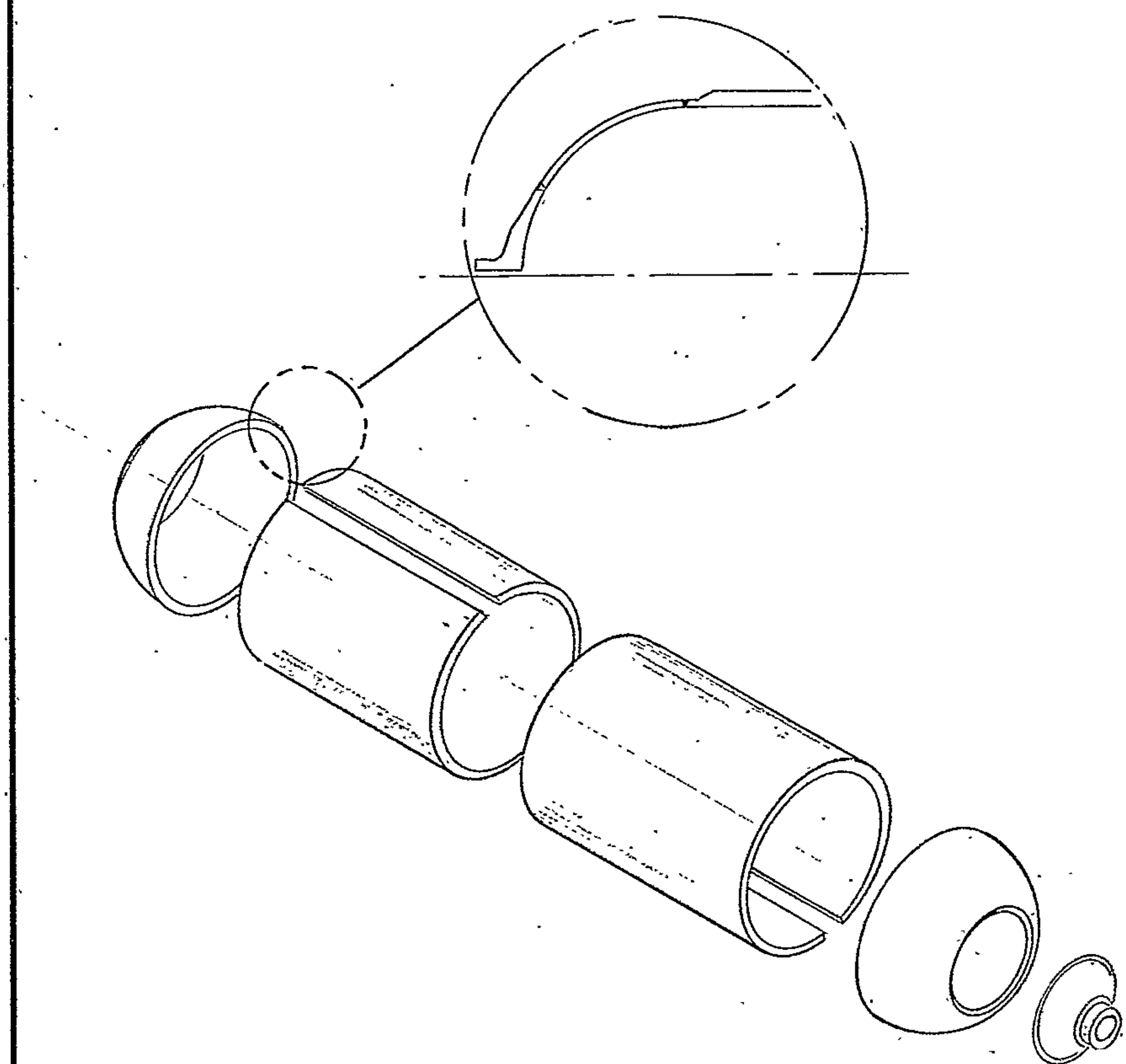
Short cylindrical sections for the vessel body were rolled to shape and size, and longitudinally butt welded, using a single pass, tungsten inert gas weld with 308 weld wire. In the heli-arc weld process a tungsten electrode is used to provide the heat input. Weld wire is fed into the area heated by the arc. Inert gas back-up and gas shielding is provided to prevent forming of oxides.

The next operation was to trim the length of the cylinders, and prepare them for girth welding. One end of each cylinder was machined to reduce the thickness from .216 inch to .145 inch to match the head thickness. (See Figure 32) The opposite end was trimmed flush.

Two cylinders were then girth welded together, with the longitudinal welds spaced 180° apart. Again, a "3 o'clock" weld was used for the first two assemblies. The parts were dye checked, X-ray inspected, and cleaned.

Bosses were welded into the heads, and the heads welded to the cylinder assembly. The assembly was dye checked, radiographically inspected, cleaned, annealed and cold pickled, in accordance with the appropriate Arde Specifications.

Serial numbers one and two were processed first, with a "3 o'clock" weld, as described in Section IV B. After welding, the parts were dye checked and radiographically inspected. It was necessary to make several weld repairs due to undercutting and porosity on the parts at this time. Serial number two parts had what was considered excessive weld repairs, but the decision was made to continue fabrication of the vessel as a weld development vessel. The weld investigation outlined in Section IV B was now progressing to the stage where pressurized gas back-up welding was being studied as a likely candidate for assembly of the two deliverable vessels.



ASSEMBLY of WELDED BOTTLE

FIGURE 32

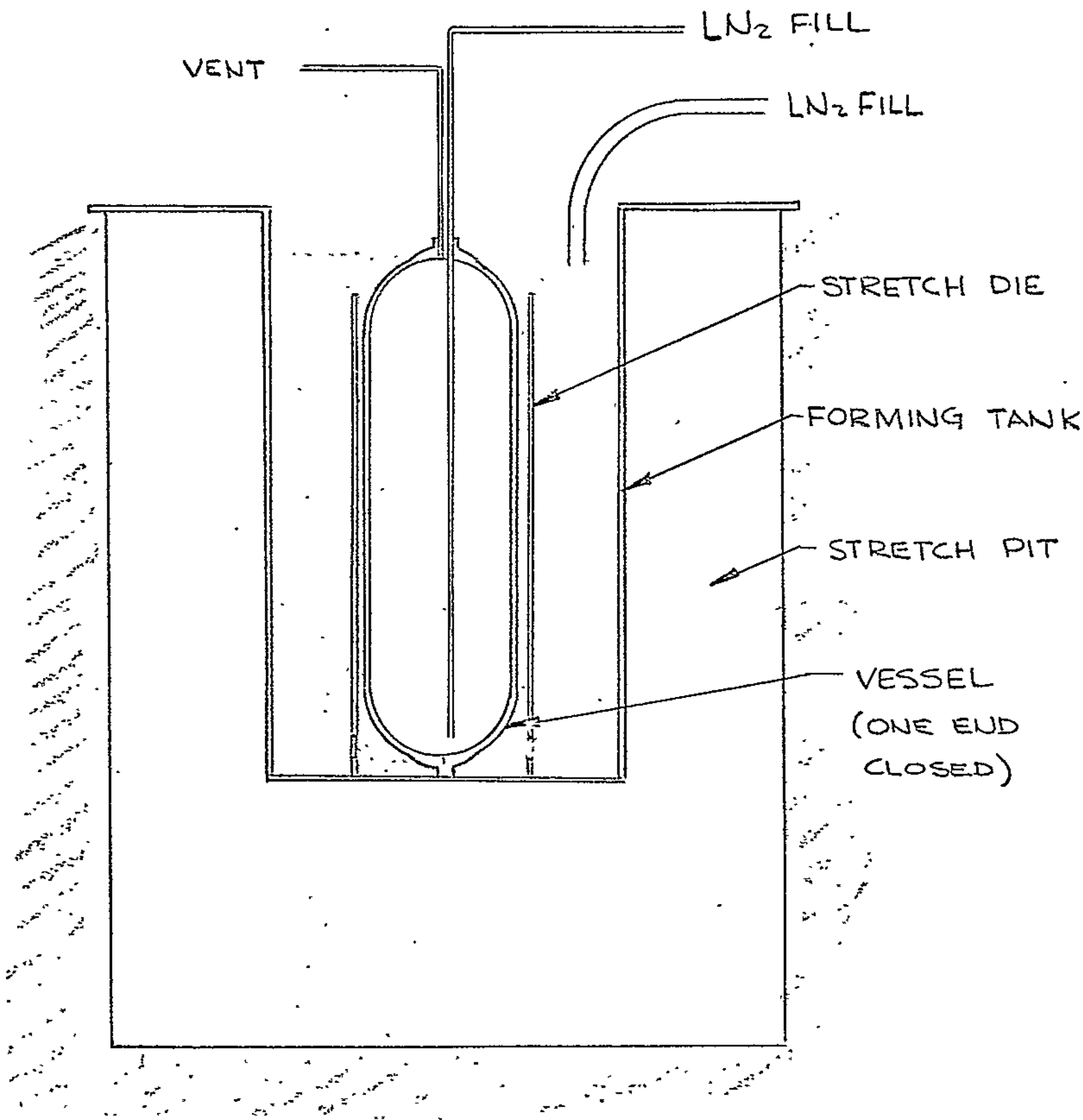
The first two vessels were then scheduled for the cryogenic stretching operation. The cylindrical stretch die was placed in stretch pit in order to confine the cylindrical portion of the vessel and control the diameter. (See Figure 33) A"free-form" stretch, where no die is employed, can result in a barrel-shaped vessel.

The forming tank in the pit was filled with liquid nitrogen to a level covering the die, and allowed to cool down. The vessel was next inserted into the die, and cooled down by flowing liquid nitrogen through it. Blast protection was placed over the pit as a precaution.

The vent valve was closed when cool down was achieved, and the pressure was brought to 10,000 psi. The vent valve was opened, and the system bled down to atmospheric pressure. The vessel was easily removed from the die because of "spring back" when the pressure is relieved. See Figure 58.

Serial number one vessel was successfully stretched at a pressure of 10,000 psi and removed from the pit for dimensional check. The dimensions before and after stretch are shown on Figure 34.

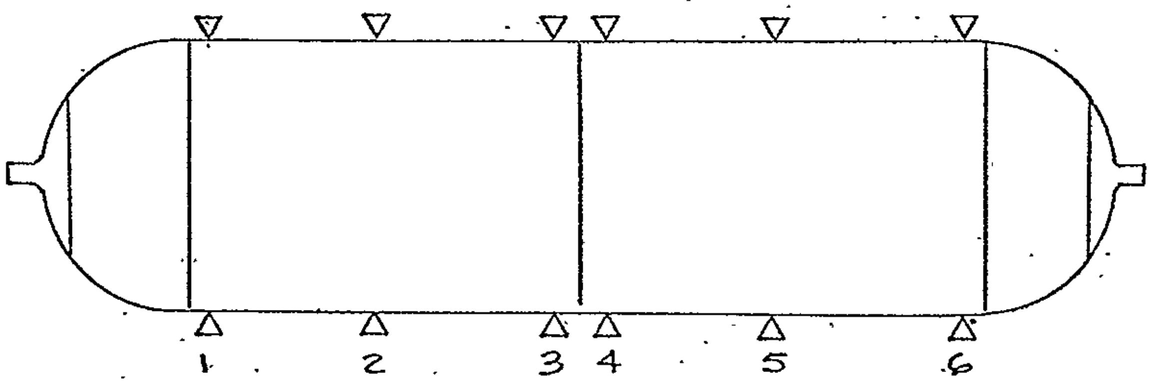
Vessel serial number two was then stretched using the foregoing procedure. At 4000 psi, a small crack opened in a repaired section of the longitudinal weld. (See Figure 35) The vessel is repairable in that there is no evidence of tearing or distortion. However, since it has been partially stretched, design strength cannot be reached in the stretch die on a restretch. If diametral control were disregarded, the unit could be annealed after repair, and cryogenically restretched to the desired strength level.



STRETCH SET-UP

FIGURE 33

D3433 ROLL & WELD VESSEL S/N 1



PREFORM

DIA	1	11.420	DIA	4	11.375
	2	11.412		5	11.423
	3	11.405		6	11.412

POSTFORM

DIA	1	12.450	DIA	4	12.525
	2	12.526		5	11.423
	3	12.520		6	11.412

STRETCH PRESSURE: 10,000 PSI

(9.94% STRETCH)

FIGURE 34

ROLL AND WELD VESSEL

Failure in Repair Weld
at 400 psi

Roll and weld vessels, serial number three and four, were fabricated in the same manner as the previous two vessels, except for the welding techniques employed. After completion of the weld development program, and the unsuccessful stretching of serial number two, the pressurized inert gas back-up technique, as described in Section IV B, was used throughout the remainder of the program. Figure 36 shows a pressurized gas back-up head to cylinder weld.

After welding, the vessels were processed in the manner described previously, and cryogenically stretched at 10,000 psi. The dimensions before and after stretch are shown in Figures 37 and 38, and the vessels in Figure 39. These roll and weld helium bottles were shipped to NASA for evaluation.

Serial number one was placed in the forming tank without the stretch die, in order to accomplish the requirement for cryogenic burst test. After cool down, the unit was taken to a pressure of 10,850 psi before burst occurred. This represented a nominal hoop stress of 337,000 psi.

A review of Figures 40 and 41 will indicate that failure initiated in the parent material (just above the identification card in Figure 41) and did not follow any weld zones. In most welded vessels, failure lines will "ring" girth welds rather than cross them as in this case.

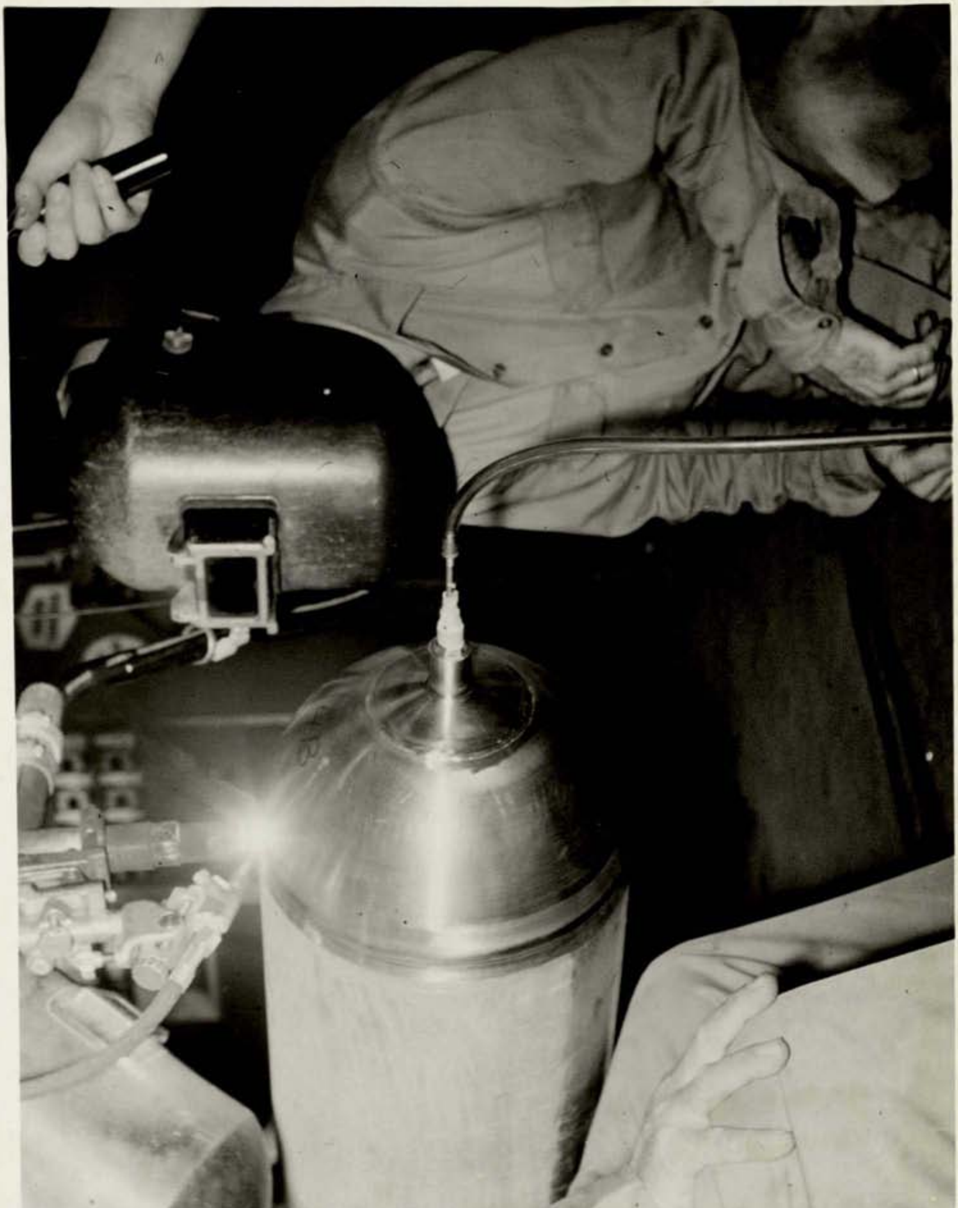
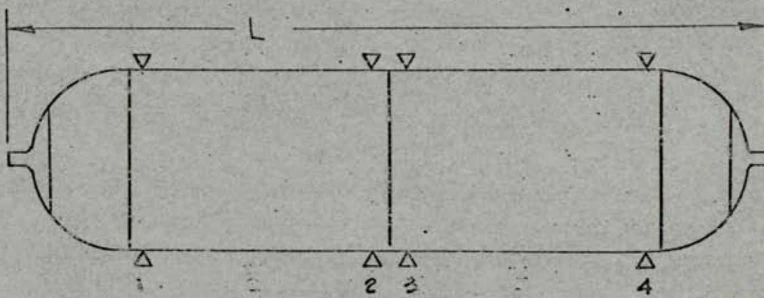


FIG. 36

D 3433 ROLL & WELD VESSEL S/N 3



PREFORM

DIA	1	11.420	L = 47.562
	2	11.405	WEIGHT = 92.1 LBS.
	3	11.400	
	4	11.395	

POSTFORM

DIA	1	12.445	L = 48.025
	2	12.511	WEIGHT = 92.11 LBS
	3	12.510	VOLUME = 2.24 CU. FT.
	4	12.435	

STRETCH PRESSURE 10,000 PSI

(9.7 % STRETCH)

FIGURE 37

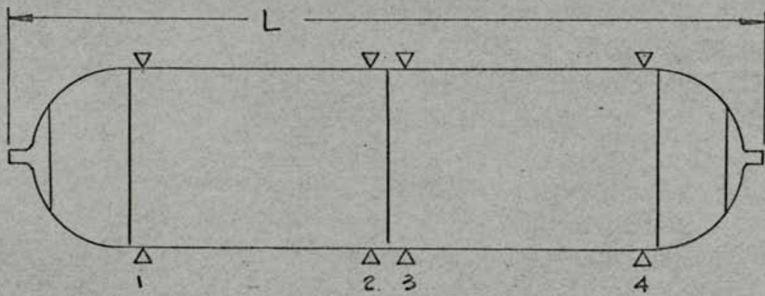
ARDE-PORTLAND, INC.

PAGE__________

REPORT NO.__________ JOB NO.__________

PREPARED BY__________ DATE__________

D 3433 ROLL & WELD VESSEL S/N 4



PREFORM

DIA	1	11.408	L = 47.332
	2	11.378	WEIGHT = 91.7 LBS
	3	11.375	
	4	11.397	

POSTFORM

DIA	1	12.426	L = 48.787
	2	12.504	WEIGHT = 91.7 LBS.
	3	12.515	VOLUME = 2.27 CU.FT.
	4	12.468.	

STRETCH PRESSURE 10,000 PSI

(5.96 % STRETCH)

FIGURE 38

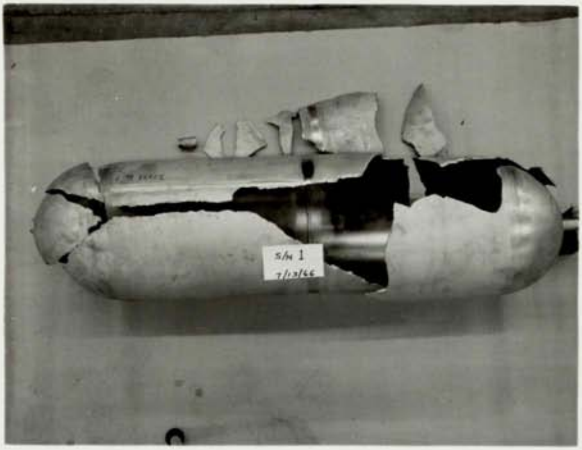
ROLL AND WELD VESSEL

S/N 3

After Cryogenic Stretch at 10,000 psi

FIG. 39

ROLL AND WELD VESSEL



S/N 1

Cryogenic Burst at 10,850 psi

FIG. 40

FIG. 41

B. Integral Vessel

Allegheny-Ludlum Steel Corporation shipped ten 11 1/2" round cornered squares (billets) directly to the Ladish Company upon material approved by Arde-Portland. Two heats of material were involved as noted in Section IV A. Billets from heat 7-2067 were designated US-1 through US-5, and billets from heat 7-2099 as CF-6 through CF-10. These serial numbers were then maintained throughout the program. Ladish proceeded to forge spin blanks and rough machine them 10 3/4 inch I.D. by 15/16 inch wall by 24 1/4 inch long. They were solution annealed at 1950°F for one hour, and water quenched. Hardness was checked and found to be 90 on the Rockwell "B" Scale. Micro cleanliness and chemistry were checked by Ladish and reported. See Tables XXV and XXVI. A comparison of these figures with those presented in Tables II and III will show comparable results.

Ultrasonic inspection was also performed on the forgings by Ladish per the methods outlined in MIL-STD-271C for longitudinal and shear wave inspection. Their report is shown in Table XVII.

The forgings were shipped to the Parsons Corporation for the fabrication of seamless cylinders.

TABLE XXV

FORGING MICROCLEANLINESS

Inclusion Type	US-1 thru US-5 (heat 7-2067)	CF-6 thru CF-10 (heat 7-2099)
Sulfide	1 thin, 0 heavy	1/2 thin, 0 heavy
Alumina	none	none
Silicate	none	none
Globular Oxide	2 thin, 1/2 heavy	1 1/2 thin, 1 heavy

TABLE XXVI

CHEMICAL ANALYSIS OF FORGINGS

	Specification (Arde 0017)	US-1 thru US-5 (Heat 7-2067)	CF-6 thru CF-10 (Heat 7-2099)
Carbon	.055 - .075	.060	.060
Manganese	1.00 - 1.70	1.22	1.31
Silicon	.30 - .70	.41	.57
Chromium	17.00 - 17.50	17.20	17.20
Nickel	7.30 - 7.60	7.63	7.43
Nitrogen	.02 - .04	.04	.03
Phosphorous	.015 max.	$<$ .01	$<$ .01
Sulfur	.015 max.	.004	.003
Oxygen	60 ppm max.	30 ppm	44 ppm
Hydrogen	2 ppm max.	$<$ 2 ppm	3 ppm

TABLE XXVII

ULTRASONIC INSPECTION REPORT

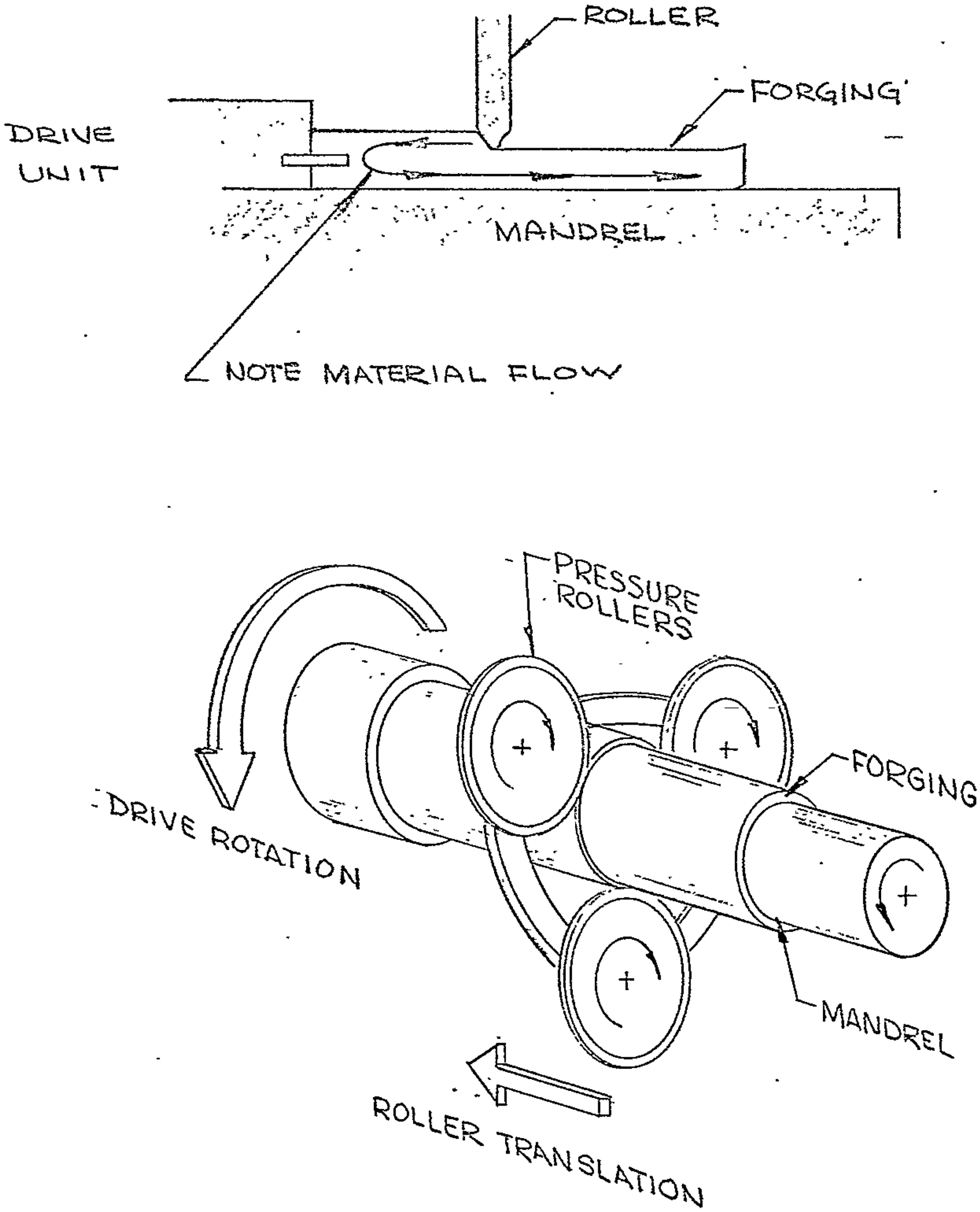
Equipment:	Immerscope model
Method:	Immersion
Wave Form:	Longitudinal and Shear
Couplant:	Water 2" water path distance
Crystal:	3/4" dia. Lithium Sulfate
Test Frequency:	5.0 mc Instrument calibrated to produce a longitudinal wave: 50% peak vs 3/64" dia. flat bottom hole
Test Frequency:	2.25 mc. Shear wave: 80% peak vs 3% notch on cylinder O.D.
Procedure:	Longitudinal wave inspection on 100% of part volume. Testing done from O.D. Shear wave inspection from O.D. in two opposite directions
Results:	Discrete indications - none Penetrability - 100% penetration obtained on all pieces with maximum of two harmonics Metal noise - US-3 and US-5 show 30% max. all others show 15% max.

The shear forming machine used to floturn the cylinders utilizes three cam-positioned pressure rolls to work the forging against a hardened and ground mandrel. As the forging diameter is cold reduced, the metal is forced out along the rotating mandrel by the rolls on the traversing carriage (See Figure 42).

The forgings were inspected, and machined on the O.D. and I.D. to fit the mandrell and achieve the desired wall thickness (See Tables XXVIII and XXIX). Figure 43 shows the forging being placed on the mandrel of the floturning machine.

Tube Number U.S. 1 was floturned from 0.704" to 0.294" without annealing. During the 5th pass the tube cracked in the longitudinal direction. This crack occurred at about 50% cold reduction. The Brinell hardness conversion of the scleroscope readings indicate a full hard condition at the end of pass number 2. Passes 3 and 4 involved an additional 19% cold work in the full hard range. All data may be found in Table XXX.

Tube Number U.S. 2 was machined to approximately the same dimensions prior to the first cold working pass as U.S. 1, however, the first annealing operation occurred after 24% cold-working and a BHN value of approximately 337 or 168,000 psi which is in the half hard condition (approaching three-quarter (3/4) hard condition). The first anneal reduced the part to the full annealed condition (BHN 140). The balance of cold work induced for the balance of this tube never exceeded the one-half (1/2) hard condition prior to annealing. All data may be found in Table XXXI.



FLOTURNING PROCESS

FIGURE 42

TABLE ~~XXVIII~~

SERIAL NO.

360° 90° 180° 270°

As Received Cylinder ARDE 301SS

TUBE NO.	LENGTH	WALL THICKNESS ▷2 A END	WALL THICKNESS ▷2 B END	AVERAGE O.D. A END	AVERAGE O.D. CENTER	AVERAGE O.D. B END	AVERAGE I.D. A END	AVERAGE I.D. B END	FINISH O.D.	FINISH I.D.	HARDNESS RB ▷1 ▷2 A END	HARDNESS RB CENTER	HARDNESS RB B END
U.S. 1	26.550"	.996	.991	12.710	12.706	12.700	10.718	10.718	RMS 90	RMS 115	90.0	89.0	89.0
		.999	.991								90.0	90.0	90.0
		.996	.994								89.0	85.0	89.0
		.997	.993								85.0	89.0	86.8
U.S. 2	24.660	.995	.989	12.735	12.735	12.730	10.755	10.750	RMS 110	RMS 75	85.0	85.0	86.8
		.994	.989								89.0	89.0	85.0
		.985	.991								85.0	85.0	85.0
		.994	.988								89.0	86.8	85.0
U.S. 5	26.020	.980	.990	12.716	12.715	12.715	10.760	10.732	RMS 140	RMS 160	85.0	86.8	86.8
		.974	.991								86.8	89.0	86.8
		.976	.993								89.0	86.8	85.0
		.996	993								89.0	89.0	89.0
C.F. 9	25.790	1.010	.985	12.700	12.697	12.690	10.681	10.711	RMS 130	RMS 90	86.8	86.8	85.0
		.995	.984								89.0	86.8	89.0
		1.009	.994								86.8	86.8	86.8
		.974	.990								89.0	89.0	86.8
C.F. 10	25.600	.993	.970	12.702	12.698	12.698	10.707	10.738	RMS 80	RMS 110	89.0	89.0	86.8
		.994	.975								89.0	85.0	89.0
		1.002	.990								86.8	89.0	89.0
		.997	.987								86.8	89.0	85.0

▷1 CONVERTED FROM SCLEROSCOPE
▷2 READINGS AT 360°, 90°, 180° & 270°

108-A

108-B

TABLE ~~XXVIII~~

-108-C

6-28-66 [illegible]

SERIAL No.
360° / 90° / 180° / 270°

TABLE XXIX

Cylinder After Machining

ARDE 301 S.S.

TUBE NO.	LENGTH	WALL THICKNESS [1] A END	WALL THICKNESS [1] B END	AVERAGE O.D. A END	AVERAGE O.D. CENTER	AVERAGE O.D. B END	AVERAGE I.D. A END	AVERAGE I.D. B END	FINISH O.D.	FINISH I.D.	AVERAGE WALL A END	AVERAGE WALL B END	HARDNESS R_B [1][2] A END	HARDNESS R_B CENTER	HARDNESS R_B B END
US 1	26.4[illegible]0	.701 .702 .700 .701	.704 .704 .703 .701	12.366	12.366	12.367	10.964	10.96[illegible]	RMS 45	RMS 18	.701	.703	85.0 86.8 86.8 85.0		85.0 86.8 86.8 85.0
US 2	24.660	.699 .704 .705 .701	.703 .704 .704 .704	12.372	12.371	12.372	10.964	10.964	RMS 50	RMS 38	.702	.704	86.8 86.8 90.0 89.0		89.0 86.8 86.8 89.0
US 5	26.000	.701 .703 .697 .695	.704 .711 .709 .706	12.380	12.383	12.384	10.980	10.976	RMS 70	RMS 35	.700	.704	85.0 85.0 83.5 85.0		83.5 83.5 85.0 83.5
CF 9	25.640	.703 .708 .700 .695	.706 .706 .704 .705	12.366	12.366	12.367	10.964	10.957	RMS 28	RMS 11	.701	.705	90.0 90.0 89.0 89.0		89.0 89.0 86.8 86.8
CF 10	25.480	.702 .702 .698 .698	.701 .701 .700 .701	12.35[illegible]	12.356	12.359	10.95[illegible]	10.957	RMS 6	RMS 4	.700	.70[illegible]	85.0 85.0 85.0 86.8		85.0 86.8 85.0 86.8

[1] CONVERTED FROM SCLEROSCOPE

[2] READINGS FROM 360°, 90°, 180°, 270°

109-A

109-B

TABLE XXIX

-109-C

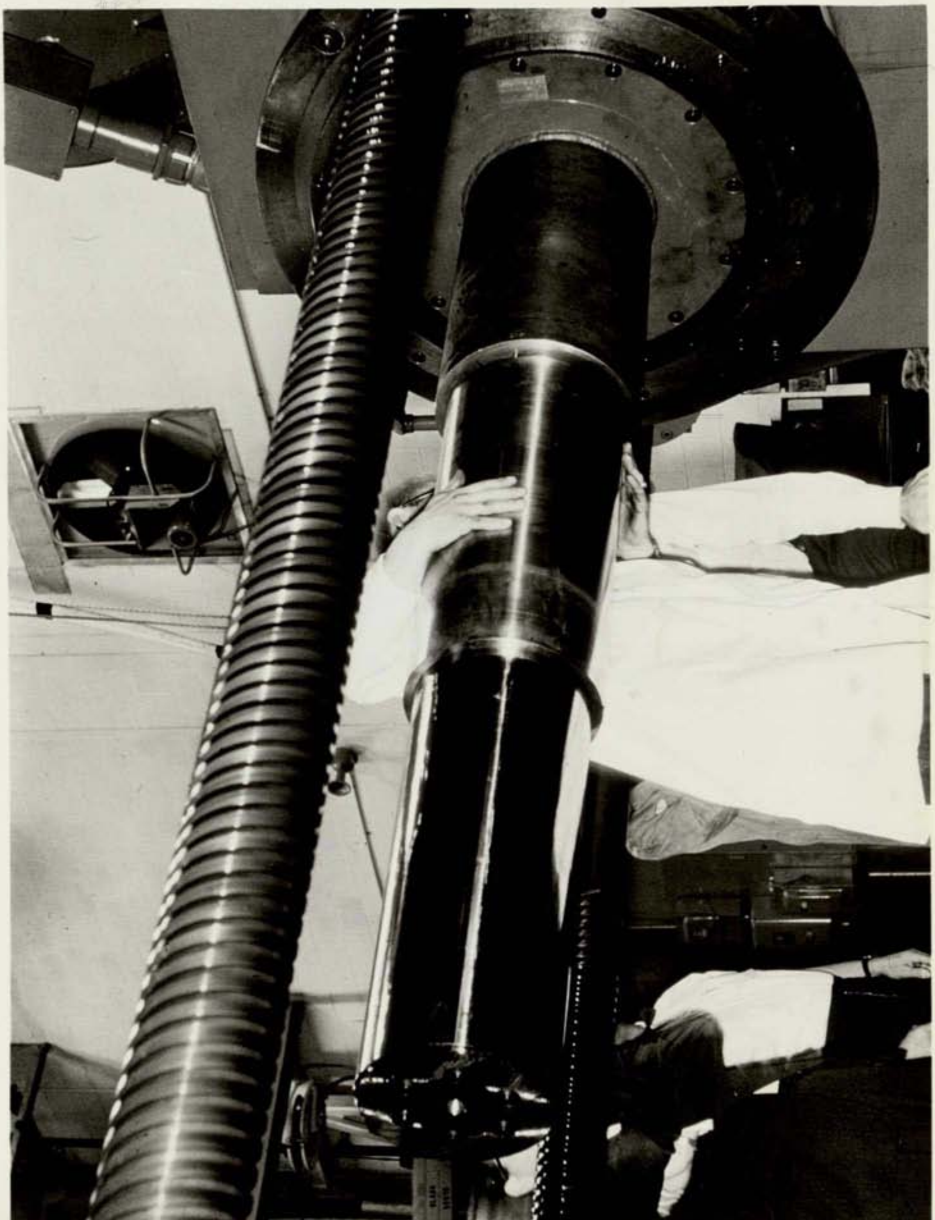


FIG. 43

TITLE PREPARED BY APPROVED BY

Parsons Corporation

PAGE NO
REPORT NO 58-10
DATE

TABLE XXX

SERIAL NO.
360° 90° 180° 270°

Flowed Tunnel
U.S. 1

Pass	% Red	Set	Speed	Feed	Amp.	Length	Flow Length	Wall Thickness			Average O.D.			Average I.D.		Average Wall		Finish		Hardness Rc		Comments
								A End	Center	B End	A End	Center	B End	A End	B End	A End	B End	O.D.	I.D.	A End	B End	
1								.618		.620	12.249	12.243	12.228	11.012	10.993	.6185	.6175	15	18	37.9	35.5	
								.618		.617										37.9	36.0	Avg BHN – A End 360
								.618		.615										39.1	36.0	B End 340
								.620		.618										34.3	36.0	
2								.502		.505	12.030	12.033	12.025	11.026	11.021	.502	.502	19	11	40.4	40.4	
								.501		.500										40.4	41.8	Avg BHN – A End 376
								.501		.500										41.1	39.7	B End 374
								.503		.504										41.1	39.7	
3								.391		.384	11.830	11.845	11.845	11.047	11.048	.3915	.3843	Not Registering	34	39.7	37.9	A End Harness Recheck – 40.4, 40.4, & 41.1
								.391		.384										39.7	37.9	
								.392		.384										37.9	37.9	Avg BHN A End 380
								.392		.386										39.7	39.7	
4								.298	298	.296										42.5	41.8	Small Lengthwise Cracks
								.298	298	.295										42.5	41.8	Split Full Length in Two Locations 160° Apart
								.298	298	.292										41.8	41.8	
								.299	301	.294										41.8	41.8	Avg BHN – A End 390

B End .388

[1] Readings At 360°, 90°, 80°, 270° Pespectively

% Reduction From Original Stock Before Flow

All Hardness Readings Converted From Sclerescope

111-A

111-B

TABLE XXX
-111-C

PAGE NO.
REPORT NO. M-658-
DATE

APPROVED BY

SERIAL No
360° 90° 180° 270°

Flowed Tunnel
U.S. 2

TABLE XXXI

1. Readings At 360°, 90°, 180°, 270° Respectively
2. Hardness Readings Converted From Scleroscope
3. Reduction Taken From Preceding Anneal

Pass	% Red. 3	Set	Speed	Feed	Amp	Length	Flow Length	Wall Thickness 1			Average O.D.			Average I.D.			Average Wall			Hardness 2 1		Comments
								A End	Center	B End	A End	Center	B End	A End	Center	B End	A End	Center	B End	A End	B End	
1								.620		.620	12.255	12.248	12.243	11.003		10.999	.626		.622	36. Rc	36 Rc	Surface Finish Good-Small Fish Scale Type
								.628		.623										36 Rc	35.5 Rc	Average BHN - A End 337
								.631		.626										36 Rc	35.5 Rc	B End 334
								.626		.623										36.6 Rc	36 Rc	
2								.526		.530	12.084	12.092	12.079	11.020		11.013	.532		.533	36 Rc	37.9 Rc	Average BHN A End 337
								.534		.532										36 Rc	36.6 Rc	B End 343
								.536		.536										36 Rc	36 Rc	
								.533		.533										36.6 Rc	36.6 Rc	
	FIRST ANNEAL 1910°F / 40 MIN WATER QUENCH SEVERE DISTORT-ION							.523		.524	12.055	12.056	12.050	10.999		10.994	.528		.528	76.4 RB	76.4 RB	Penetrant Showed Very Shallow Porosity
								.531		.531										80.8 RB	78.7 RB	Average BHN - A End 142
								.532		.532										78.7 RB	78.7 RB	B End 140
								.527		.526										76.4 RB	76.4 RB	
3								.504		.506	12.009	12.015	12.000	10.991		10.984	.509		.508	30.9 Rc	30 Rc	Heavy Roll Pick up Marking .003 Deep -
								.511		.509										31.5 Rc	30.9 Rc	Removed
								.513		.511										30.9 Rc	30.9 Rc	Average BHN - A End 293
								.510		.507										30 Rc	30.9 Rc	B End 292
4								.442		.441	11.902	11.913	11.904	11.010		11.014	.446		.445	32.1 Rc	34.3 Rc	Light Surface Marks Of .001 About 15
								.446		.444										32.1 Rc	33.1 Rc	Places - Removed
								.449		.447										32.1 Rc	31.5 Rc	Average BHN - A End 301
								.446		.446										31.5 Rc	31.5 Rc	B End 308
5								.406	.409	.404	11.830	11.855	11.833	11.012	11.034	11.017	.409	.410	.408	32.1 Rc	32.1 Rc	Light Surface Indications Of .005
								.411	.411	.407										31.5 Rc	32.1 Rc	
								.411	.412	.412										31.5 Rc	32.1 Rc	Average BHN - A End 300
								.409	.410	.408										31.5 Rc	31.5 Rc	B End 301
	SECOND ANNEAL 1910°F / 40 MIN. AIR COOL							.392	.395	.392	11.800	11.822	11.804	11.010	11.029	11.016	.395	.3965	.3945	86.8 RB	82.9 RB	Penetrant Shows Heavy Porosity O.D.
								.396	.396	.395										86.8 RB	85.0 RB	Ovality A End - .305
								.398	.397	.399										86.8 RB	85.0 RB	B End - .578
								.395	.398	.397										82.9 RB	82.9 RB	Average BHN - A End 167 B End 160
6								.368	.374	.372	11.755	11.761	11.753	11.011	11.013	11.009	.372	.374	.372	31.5 Rc	30.9 Rc	Average BHN A End 289
								.374	.374	.370										29.9 Rc	27.6 Rc	B End 283
								.373	.375	.373										28.8 Rc	28.8 Rc	
								.374	.376	.372										30.9 Rc	30.9 Rc	

112-A

112-B

TABLE XXXI (1)

P. 112 C

6-30-66 RTN.

TABLE XXXI (Cont.)

Pass	% Red	Set	Speed	Feed	Amp	Length	Flow Length	Wall Thickness ▷ A End	Center	B End	Average O.D. A End	Center	B End	Average ID A End	Center	B End	Average Wall A End	Center	B End	Hardness ▷▷ A End	B End	Comments
7								.325	.329	.326	11.680	11.696	11.679	11.024	11.036	11.025	.328	.330	.327	28.8 Rc	28.8 Rc	Average BHN A End - 277 B End - 279
								.329	.330	.327										27.6 Rc	30.9 Rc	
								.329	.332	.328										28.8 Rc	28.8 Rc	
								.330	.330	.327										29.9 Rc	27.6 Rc	
8								.290	.295	.293	11.628	11.655	11.619	11.042	11.063	11.033	.293	.296	.293	27.6 Rc	25.4 Rc	Average CHN A End- 267 B End- 264
								.295	.296	.292										26.6 Rc	26.6 Rc	
								.294	.298	.295										27.6 Rc	27.6 Rc	
								.294	.296	.290										27.6 Rc	27.6 Rc	
THIRD ANNEAL 1910°/40 MIN. AIR COOL								.289	.293	.288	11.585	11.615	11.588	11.003	11.027	11.012	.291	.294	.288	50.8 RB	80.8 RB	Average BHN A End- 139 B End- 140
								.293	.295	.290										78.7 RB	76.4 RB	Penetrant Acceptable
								.292	.295	.292										76.4 RB	76.4 RB	Ovality Not Acceptable
								.290	.294	.288										72.0 RB	76.4 RB	
9								.278	.277	.272	11.583	11.592	11.532	11.025	11.034	10.982	.279	.279	.275	22.8 Rc	24.2 Rc	Average BHN A End- 238 B End- 245
								.280	.280	.273										21.7 Rc	22.8 Rc	
								.280	.280	.278												
								.278	.279	.276												
10								.259	.260	.252	11.535	11.583	11.517	11.017	11.069	11.005	.259	.261	.256	24.2 Rc	22.8 Rc	Average BHN A End- 246 B End- 238
								.262	.263	.255										22.8 Rc	21.7 Rc	
								.259	.262	.261										24.2 Rc	21.7 Rc	
								.258	.261	.256										24.2 Rc	22.8 Rc	
11								.220	.225	.220	11.471	11.541	11.485	11.035	11.087	11.039	.223	.226	.223	24.2 Rc	24.2 Rc	Average BHN A End- 246 B End- 246
								.224	.227	.221										25.4 Rc	24.2 Rc	
								.224	.228	.228										22.8 Rc	24.2 Rc	
								.224	.226	.225										22.8 Rc	22.8 Rc	
FINAL INSPECTION								.225	.227	.222	11.475	11.548	11.463				.223	.225	.217			Penetrant Cracked – Stress Relieved 500° @ 8 Hrs. – Finish OD 40 RMS ID. 30 RMS
								.223	.224	.218												
								.220	.224	.213												
								.224	.226	.218												

112-D 112-E

TABLE XXXI (2)

Tube Number U.S. 5 was completed after nine (9) passes with three intermediate anneals without difficulty, except that one small crack on the O.D. was discovered after Pass number 7. This crack was approximately 0.010" deep and was removed by sanding. This crack appeared after approximately 32% cold work. Data may be found in Table XXXII.

Tube Number CF-9 was completed in ten (10) passes with three intermediate anneals with total reductions between each anneal of similar values as U.S. 5. Light cracking again occurred on Pass Number 7 at approximately 30% cold work reduction. Cracks were removed by sanding. All data is available in Table XXXIII. Figure 44 shows cylinders after intermediate interpass annealing.

Tube Number CF-10 was carried through the first anneal in a similar manner as the previous tube which resulted in annealed hardnesses of the half (1/2) hard rather than full annealed values. Pass Number 3 at 17% reduction resulted in hardness approaching the full hard condition. Pass Numbers 4 and 5 following the second anneal were cold worked approximately 16% and 14% and light cracking was in evidence after each pass. After the third anneal no difficulty was experienced in the cold working operations (which at no time exceeded 12% reduction in a single pass). All data may be found in Table XXXIV.

This report does not cover in detail Tube Numbers U.S. 3, U.S. 4, C.F. 6, C.F. 7, and C.F. 8, inasmuch as data was either limited or total reductions were not achieved. Briefly, the following are the results for those cylinders.

TITLE:

PREPARED BY

APPROVED BY

Parsons

DATE

TABLE ~~XXXII~~ (CONT'D.)

Pass	No. Rev.	Set	Speed	Feed	Amp	Length	Flow Length	Wall Thickness A End	Wall Thickness Center	Wall Thickness B End	Average O.D. A End	Average O.D. Center	Average O.D. B End	Average I.D. A End	Average I.D. Center	Average I.D. B End	Average Wall A End	Average Wall Center	Average Wall B End	Hardness A End	Hardness B End	Comments
7								.275	.277	.273	11.580	11.632	11.593	11.028	11.078	11.045	.276	.277	.274	30.9 Rc	30.9 Rc	Average BHN - A End 297
								.278	.278	.273										32.1 Rc	31.5 Rc	B End 297
								.276	.276	.277										31.5 Rc	32.1 Rc	One Crack (010) Removed From O.D.
								.274	.278	.293										31.5 Rc	31.5 Rc	
	THIRD ANNEAL 1910° F / 40 MIN. AIR COOL							.271	.272	.269	11.543	11.594	11.550	11.002	11.050	11.010	.2705	.272	.270	82.9 RB	82.9 RB	Average BHN - A End 160
								.273	.272	.269										82.9 RB	82.9 RB	B End 158
								.270	.272	.274										85.0 RB	85.0 RB	Ovality - A End .180
								.268	.272	.268										85.0 RB	82.9 RB	B End .187
8								.254	.257	.252	11.515	11.549	11.497	11.007	11.037	10.994	.254	.256	.254	30.9 Rc	30.4 Rc	Average BHN - A End 280
								.256	.257	.250										30.4 Rc	30.4 Rc	B End 277
								.254	.254	.255										27.6 Rc	27.6 Rc	
								.252	.256	.254										27.6 Rc	26.6 Rc	
9								.222	226	.223	11.464	11.520	11.498	11.018	11.070	11.052	223	.225	.223	27.6 Rc	25.4 Rc	Average BHN - A End 262
								.224	.226	.224										25.4 Rc	25.4 Rc	B End 255
								.226	.223	.225										26.6 Rc	25.4 Rc	Stress Relieved 8 Hrs. @ 500°
								.221	.225	.222										26.6 Rc	25.4 Rc	
	FINAL INSPECTION							.223	.222	.233	11.490	11.518	11.463	11.050	11.074	11.023	.220	.222	.220			Penetrant Checked Finish - O.D. 10 RMS I.D. 23 RMS
								.220	.223	.219												
								.216	.222	.218												
								.221	.219	.219												

114-D

114-E

TABLE ~~XXXII~~ (2)

6-30-66 R.T.N.

FORM 605-1003 11.59

APPROVED BY

Parsons.

DATE 11-658-10

Serial No.

360° / 90° / 180° / 270°

TABLE XXXII

Flowed Tunnel
U. S. 5

1 ▷ Readings At 360°, 90°, 180°, 270° Respectively
2 ▷ Hardness Readings Converted From Sclerescope
3 ▷ Reduction Taken From Preceding Anneal

Pass	% Red. (3)	Set	Speed	Feed	Amp	Length	Flow Length	Wall Thickness (1) A End	Wall Thickness Center	Wall Thickness B End	Average O.D. A End	Average O.D. Center	Average O.D. B End	Average I.D. A End	Average I.D. Center	Average I.D. B End	Average Wall A End	Average Wall Center	Average Wall B End	Hardness (1)(2) A End	Hardness B End	Comments
1								.634 .639 .628 .628		.627 .628 .631 .627	12.278	12.280	12.278	11.014		11.022	.632		.628	39.6 Rc 37.9 Rc 39.6 Rc 37.9 Rc	36.0 Rc 36.0 Rc 36.6 Rc 36.0 Rc	Average BHN-A End 361 B End 337
2								.534 .538 .531 .533			12.090	12.090	12.088	11.022		11.028	.534		.530	36.6 Rc 36.6 Rc 37.9 Rc 36.6 Rc	36.0 Rc 37.9 Rc 34.3 Rc 33.1 Rc	Average BHN-A End 344 B End 330
FIRST ANNEAL (1910°F. /40 MIN - AIR COOL)								.528 .531 .524 .524		.523 .531 .532 .524	12.064	12.060	12.046	11.010		11.991	.527		.5275	82.9 RB 82.9 RB 85.0 RB 80.8 RB	82.9 RB 82.9 RB 85.0 RB 82.9 RB	Average BHN - A End 156 B End 158 Penetrant Check O.K.
3								.465 .461 .460 .465		.457 .465 .459 .459	11.964	11.986	11.916	11.036		10.996	.464		.460	37.9 Rc 36.6 Rc 37.9 Rc 37.9 R	35.5 Rc 36.0 Rc 36.6 Rc 36.0 Rc	Average BHN - A End 349 B End 335 Light Markings On O.D. (.001) Removed With Sanding Disc.
4								.411 .412 .408 .407		.405 .412 .407 .404	11.870	11.888	11.858	11.050		11.044	.410		.407	36.6 R 37.9 Rc 37.9 Rc 39.1 Rc	36.6 Rc 37.9 Rc 39.1 Rc 39.1 Rc	Average BHN - A End 352 B End 355 Some Marking O.D.
SECOND ANNEAL (1910°F/40 MIN - AIR COOL)								.408 .414 .404 .405	.410 .410 .408 .408	.397 .402 .398 .396	11.840	11.859	11.804	11.024	11.041	11.008	.408	.409	.398	76.4 RB 72.0 RB 69.8 RB 72.0 RB	72.0 RB 69.8 RB 69.8 RB 72.0 RB	Average BHN A End 128 Penetrant O.K B End 124 Ovality - A End .310" B End .307"
5								.390 .391 .383 .385	.389 .393 .386 .387	.382 .383 .383 .377	11.795	11.800	11.764	11.021	11.022	11.002	.387	.389	.381	34.3 Rc 32.1 Rc 30.5 Rc 29.9 Rc	33.1 Rc 32.1 Rc 29.9 Rc 27.6 Rc	Average BHN- A End 299 B End 292
6								.334 .337 .333 .329	.334 .335 .330 .333	.332 .331 .330 .327	11.684	11.719	11.697	11.018	11.053	11.037	.333	.333	.330	31.5 Rc 30.9 Rc 33.1 Rc 31.5 Rc	32.1 Rc 28.8 Rc 30.9 Rc 27.6 Rc	Average BHN- A End 300 B End 285

114-A

114-B

TABLE XXXII (1)

-114-C

TITLE: PREPARED BY APPROVED BY

Parsons

PAGE NO. REPORT NO. M-658-10 DATE

TABLE XXXIII

Serial No. 360° 90° 180° 270°

Flowed Tunnel
C.F. 9

1 Readings At 360°, 90°, 180°, 270° Respectively
2 Hardness Readings Converted From Scleroscope
3 Reduction Taken From Preceding Anneal

Pass	% Red. 3	Set	Speed	Feed	Amp	Length	Flow Length	Wall Thickness 1			Average O.D. A End	Average O.D. Center	Average O.D. B End	Average I.D. A End	Average I.D. Center	Average I.D. B End	Average Wall A End	Average Wall Center	Average Wall B End	Hardness 1 2 A End	Hardness B End	Comments
1								.634		.629	12.282	12.270	12.248	11.007		10.990	.6325		.629	40.4 Rc	39.7 Rc	Average BHN - A End 375
								.638		.631										40.4 Rc	39.7 Rc	B End 363
								.633		.627										40.4 Rc	39.1 Rc	
								.633		.630										40.4 Rc	37.9 Rc	
2								.534		.533	12.093	12.094	12.087	11.026		11.021	.5335		.533	36.6 Rc	37.9 Rc	Average BHN - A End 339
								.536		.535										36.6 Rc	36.0 Rc	B End 344
								.532		.530										36.0 Rc	36.0 Rc	
								.532		.533										36.0 Rc	37.9 Rc	
	FIRST ANNEAL							.530		.526	12.069	12.059	12.039	11.012		10.989	.5285		.525	82.9 R_B	80.8 R_B	Average BHN - A End 154
	1910°F / 40 MIN - AIR COOL							.532		.529										80.8 R_B	82.9 R_B	B End 154
								.526		.523										82.9 R_B	82.9 R_B	Penetrant Checked O.K.
								.526		.526										82.9 R_B	82.9 R_B	
3								.468		.463	11.985	12.001	11.955	11.053		11.031	.466		.462	36.0 Rc	35.5 Rc	Average BHN - A End 343
								.468		.464										37.9 Rc	36.0 Rc	B End 330
								.463		.460										36.6 Rc	35.5 Rc	
								.464		.461										36.6 Rc	34.3 Rc	
4								.414		.410	11.880	11.895	11.869	11.054		11.053	.413		.408	39.1 Rc	36.6 Rc	Average BHN - A End 360
								.416		.409										37.9 Rc	39.1 Rc	B End 347
								.411		.407										39.1 Rc	36.6 Rc	
								.411		.406										39.1 Rc	36.6 Rc	
	SECOND ANNEAL							.412	.416	.408	11.840	11.860	11.819	11.020	11.034	11.009	.410	.413	.405	69.8 R_B	69.8 R_B	Average BHN - A End 122 Penetrant O.K.
	1910°F / 40 MIN. AIR COOL							.412	.414	.404										69.8 R_B	69.8 R_B	B End 121
								.408	.408	.401										72.0 R_B	69.8 R_B	Ovality - A End .478
								.408	.414	.407										69.8 R_B	69.8 R_B	B End .553
5								.390	.390	.385	11.794	11.806	11.771	11.014	11.030	11.015	.390	.388	.378	28.8 Rc	2 .9 Rc	Average BHN - A End 276
								.388	.388	.384										29.9 Rc	28.8 Rc	B End 271
								.386	.386	.382										29.9 Rc	26.6 Rc	O.D. Machined Twice After 5th Pass To Remove
								.384	.388	.382										25.4 Rc	26.6 Rc	Surface Indications (Approx. .020 Removed)
																				28.8 Rc	27.6 Rc	
6								.338	.336	.332	11.012	11.722	11.683	11.012	11.054	11.029	.3335	.334	.327	30.9 Rc	31.5 Rc	Average BHN - A End 298
								.332	.330	.330										32.1 Rc	31.5 Rc	B End 297
								.334	.333	.325										31.5 Rc	30.9 Rc	Heavy Pattern Of Light Cracks. Machined
								.330	.338	.321										31.5 Rc	31.5 Rc	.018 Off O.D. To Remove
		115-A													115-B							7-1-66 R.T.N.

TABLE XXXIII (CONT'D.)

PASS	% RED	SET	SPEED	FEED	AMPS	LENGTH	FLOW LENGTH	WALL THICKNESS A END	WALL THICKNESS CENTER	WALL THICKNESS B END	AVERAGE O.D. A END	AVERAGE O.D. CENTER	AVERAGE O.D. B END	AVERAGE I.D. A END	AVERAGE I.D. CENTRE	AVERAGE I.D. B END	AVERAGE WALL A END	AVERAGE WALL CENTER	AVERAGE WALL B END	HARDNESS A END	HARDNESS B END	COMMENTS
7								.286	.285	.282	11.627	11.675	11.660	11.059	11.109	11.099	.284	.283	.2805			Light Surface Cracking
								.280	.278	.280												
								.284	.284	.284												
								.285	.285	.276												
	THIRD ANNEAL							.286	.288	.280	11.589	11.632	11.579	11.019	11.062	11.017	.285	.285	.281	78.7 R_B	72.0 R_B	Average BHN - A End 137
	1910°F / 40 MIN AIR COOL							.282	.279	.285										72.0 R_B	76.4 R_B	B End 135
								.286	.287	.282										76.4 R_B	72.0 R_B	Two Crack Indications Removed Heavy Ovality In
								.287	.286	.278										78.7 R_B	80.8 R_B	The Center Of Tube
8								.278	.277	.278	11.546	11.583	11.532	10.992	11.027	10.980	.277	.278	.276	26.6 R_C	25.4 R_C	Average BHN - A End 266
								.275	.277	.278										26.6 R_C	27.6 R_C	B End 262
								.277	.278	.275										27.6 R_C	26.6 R_C	
								.277	.280	.275										26.6 R_C	26.6 R_C	
9								.259	.260	.258	11.535	11.590	11.516	11.019	11.070	11.004	.258	.260	.256	26.6 R_C	27.6 R_C	Average BHN - A End 259
								.256	.258	.256										25.4 R_C	27.6 R_C	B End 264
								.258	.262	.255										25.4 R_C	25.4 R_C	
								.259	.261	.254										26.6 R_C	26.6 R_C	
10								.228	.228	.224	11.481	11.560	11.489	11.027	11.102	11.051	.227	.229	.224	24.2 R_C	22.8 R_C	Average BHN - A End 246
								.225	.226	.226										22.8 R_C	22.8 R_C	B End 245
								.227	.230	.225										24.2 R_C	24.2 R_C	
								.229	.232	.222										24.2 R_C	24.2 R_C	
	FINAL INSPECTION							.225	.228	.222	11.477	11.559	11.488	11.029	11.101	11.038	.222	.229	.225			Penetrant O.K. - Stress Relieved 8 Hrs @ 500°
								.225	.226	.224												Finish - OD. 40 RMS
								.224	.231	.226												I.D. 30 RMS
								.222	.232	.227												

115-D

115-E

TABLE XXXIII (2)

-115-E

7-1-66 R.T.W.

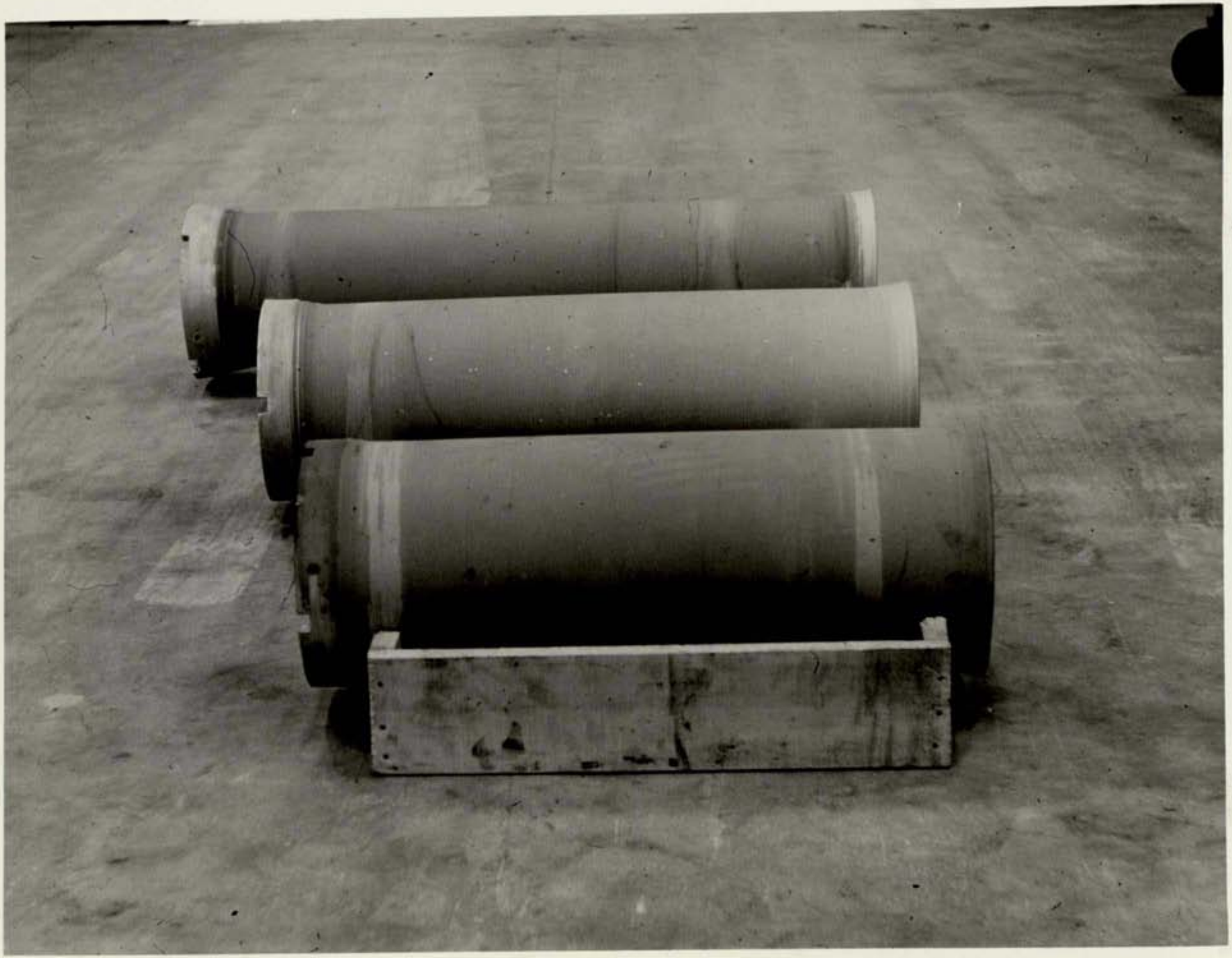


FIG. 44

TITLE. PREPARED BY APPROVED BY

Parsons

PAGE NO. REPORT NO. [illegible] DATE

Serial No. 360° 90° 180° 270°

Flowed Tunnel
C.F. 10

TABLE XXXIV

1▷ Readings At 360°, 90°, 180°, 270° Respectively
2▷ Hardness Readings Converted From Scleroscope
3▷ Reduction Taken From Preceding Anneal

Pass	% Red. 3▷	Set	Speed	Feed	Amp	Length	Flow Length	Wall Thickness 1▷ A End	Wall Thickness Center	Wall Thickness B End	Average O.D. A End	Average O.D. Center	Average O.D. B End	Average I.D. A End	Average I.D. Center	Average I.D. B End	Average Wall A End	Average Wall Center	Average Wall B End	Hardness 1▷ 2▷ A End	Hardness B End	Comments
1								.636 .633 .633 .634		.630 .627 .627 .629	12.274	12.271	12242	11.006		10.984	.634		.629	41.1 Rc 42.5 Rc 39.8 Rc 40.4 Rc	41.8 Rc 39.1 Rc 41.8 Rc 39.8 Rc	Average BHN - A End 381 B End 377
2								.535 .533 .533 .536		.536 .535 .531 .533	12.096	12.100	12.094	11.028		11.026	.534		.534	37.9 Rc 39.1 Rc 36.6 Rc 36.0 Rc	36.0 Rc 36.0 Rc 39.1 Rc 39.1 Rc	Average BHN - A End 348 B End 350 See Note 1
FIRST ANNEAL 1910°/40 MIN - WATER QUENCH SEVERE DISTORTION								.531 .529 .529 .530		.528 .526 .525 .528	12.071	12.073	12.071	11.011		11.017	.530		.527	90.0 RB 89.0 RB 89.0 RB 85.0 RB	82.9 RB 82.9 RB 80.8 RB 86.8 RB	Average BHN - A End 176 B End 158
3								.441 .444 .441 .443		.437 .434 .433 .434	11.957	11.967	11.920	11.073		11.052	.442		.4345	39.1 Rc 39.1 Rc 39.6 Rc 37.9 Rc	35.5 Rc 35.5 Rc 34.3 Rc 34.3 Rc	Average BHN - A End 362 B End 326
SECOND ANNEAL 1910°/40 MIN. - AIR COOL								.443 .427 .435 .430	.418 .422 .418 .419	.420 .424 .417 .419	11.907	11.944	11.866	11.039	11.106	11.025	.434	.419	.420	82.9 RB 82.9 RB 82.9 RB 80.8 RB	82.9 RB 80.8 RB 82.9 RB 82.9 RB	Average BHN - A End 154 B End 154 Heavy Ovality - A End .200 See Note 2 B End .345
4								.364 .364 .362 .356	.354 .356 .350 .352	.358 .352 .347 .349	11.772	11.863	11.710	11.651	11.157	11.008	.361	.353	.351	36.0 Rc 35.5 Rc 34.3 Rc 34.3 Rc	34.3 Rc 34.3 Rc 35.5 Rc 34.3 Rc	Average BHN - A End 327 B End 324 O.D. Has Half Moon Scale With Fine Cracking · Checks, Depth .035.
5								.300 .305 .300 .300	.305 .310 .302 .307	.300 .296 .294 .296	11.660	11.692	11.625	11.058	11.080	11.031	.301	.306	.297	31.5 Rc 32.1 Rc 32.1 Rc 32.1 Rc	31.5 Rc 32.1 Rc 30.9 Rc 31.5 Rc	Average BHN - A End 301 B End 298 Light Cracking O.D., Local Sanding + Belt Sand Full Surface. 001 Removed Overall, .003 Locally.
THIRD ANNEAL 1910°/40 MIN - AIR COOL								.298 .298 .298 .298	.303 .305 .300 .302	.298 .292 .291 .293	11.625	11.659	11.596	11.029	11.055	11.008	.298	.302	.294	85.0 RB 85.0 RB 85.0 RB 82.9 RB	85.0 RB 82.9 RB 82.9 RB 82.9 RB	Average BHN - A End 161 B End 158 Penetrant Showed Light Porosity I.D. [illegible], O.D. [illegible] Has Open Cracking Which Will Not Hold Penetrant. Approx. [illegible] Removed From O.D., O.D. Surface [illegible]

117-A 117-B

FORM 603-1003 11-59

TITLE: PREPARED BY APPROVED BY

Parsons

PAGE NO. REPORT NO M-658-10 DATE

TABLE ~~XXXIV~~ (CONT'D.)

Pass	No. Rls ▷3	Set	Speed	Feed	Amp	Length	Flow Length	Wall Thickness ▷1 A End	Wall Thickness Center	Wall Thickness B End	Average O.D. A End	Average O.D. Center	Average O.D. B End	Average I.D. A End	Average I.D. Center	Average I.D. B End	Average Wall A End	Average Wall Center	Average Wall B End	Hardness ▷1 ▷2 A End	Hardness B End	Comments
6								.276	.284	.284	11.565	11.594	11.552	11.007	11.028	11.002	.279	.283	.275	27.6 Rc	27.6 Rc	Average BHN - A End 267
								.286	.289	.272										27.6 Rc	28.8 Rc	B End 269
								.272	.278	.270										26.6 Rc	27.6 Rc	I.D. Has 3 Sharp Pits & Rough Scratches
								282	272	.274										27.6 Rc	26.6 Rc	
7								.255	.260	.264	11.544	11.587	11.527	11.028	11.071	11.011	.258	.258	.258	27.6 Rc	25.4 Rc	Average BHN - A End 264
								.264	.258	.257										26.6 Rc	25.4 Rc	B End 260
								.250	.258	.257										27.6 Rc	26.6 Rc	
								.262	.258	.256										25.4 Rc	27.6 Rc	
8								.220	.225	.228	11.489	11.555	11.490	11.023	11.103	11.042	223	.226	.224	25.4 Rc	22.8 Rc	Average BHN - A End 245
								228	.226	223										22.8 Rc	24.2 Rc	B End 245
								.218	.226	.218										22.8 Rc	24.2 Rc	Line Build up On I.D. Of Tube From Groove In
								.226	.226	.224										22.8 Rc	22.8 Rc	Mandrel - Stress Relieved 8 Hrs @ 500°
FINAL INSPECTION								.222	.225	.222	11.493	11.551	11.493	11.047	11.011	11.055	.223	.220	219			Penetrant Check OK.
								.218	.216	.214												Finish - O.D. 16
								223	.221	.224												I.D. 20
								.228	.218	.216												

① One Lengthwise Hairline Crack Removed With Sander, Possibly .002 Removed, One Heavy Penetrant Indication (Lap) Removed By Sanding. Over 60% Of O.D. Covered With Porosity Readings, Made By Pickup On Rolls. Removed By Polishing.

② Ovality Corrected. Penetrant Showed Heavy Indications, Removed By Sanding.

117-D 117-E

TABLE XXXIV (12)

-117-F

FORM 605-1003 11-58

Work was stopped on US-3 and 4 and CF-8 just prior to the second anneal. No significant problems were encountered, and in fact, the dimensional control from tube to tube was far superior than that achieved previously. However, the cylinders were not continued to final size inasmuch as the required parts were fabricated in the first five tries. Table XXXV shows the dimensions after each pass on these cylinders. Note that a light machining was required on US-3 after the sixth pass to remove very slight crack indications. The tube to tube variation on these three parts is ± .015" on the I.D. dimension and ± .008" on wall thickness.

Similarily, work was discontinued on tubes CF-6 and CF-7. Both showed cracks after the first anneal. There was no evidence of cracking on CF-6 prior to annealing. Light cracking was visible after the second pass on CF-7 prior to annealing.

Metallurgical examination of the forged material prior to floturning revealed a substantial variation in the amount of transformed austenitic structure which could influence cold working. There was also evidence of substantial variation in the amount of carbide precipitates (chrome carbide) from tube to tube. A combination of the above could account for some of the cracking problems encountered at relatively low reduction percentages. In the case of US-1, however, the cold work was at a level which would promote the resultant failure.

Photo micrographs of typical forged material may be seen in Figures 45 through 47. These photos were taken at 100x and are only representative rather than analytical examples. Analysis of the structure was accomplished at 1125x; however, facility photographic limitations preclude presentation of photo micrographs at this magnification.

TUBE NUMBER	BEFORE PASS ONE		1ST PASS		2ND PASS		3RD PASS	
	I.D.	WALL	I.D.	WALL	I.D.	WALL	I.D.	WALL
US-3	$10.955^{\pm.001}$	$.711^{+.002}_{-.003}$	$10.974^{\pm.004}$	$.668^{+.001}_{-.002}$	$10.095^{\pm.002}$	$.5935^{+.0015}_{-.0035}$	$11.0165^{\pm.0035}$	$.5293^{+.0037}_{-.0023}$
US-4	$10.9635^{\pm.0015}$	$.709^{+.002}_{-.007}$	$10.980^{\pm.003}$	$.6678^{+.0022}_{-.0028}$	$11.000^{\pm.001}$	$.593^{+.002}_{-.003}$	$11.019^{\pm.000}$	$.530^{+.004}_{-.002}$
CF-8	$10.9595^{\pm.0005}$	$.699^{+.006}_{-.005}$	$10.9735^{\pm.0035}$	$.666^{+.007}_{-.005}$	$10.9965^{\pm.0065}$	$.594^{+.006}_{-.005}$	$11.029^{\pm.001}$	$.530^{+.005}_{-.004}$
	4TH PASS		**5TH PASS**		**6TH PASS**		**MACHINED**	
	I.D.	WALL	I.D.	WALL	I.D.	WALL	I.D.	WALL
US-3	$10.991^{+.011}_{-.001}$	$.508^{+.006}_{-.007}$	$11.007^{+.005}_{-.003}$	$.448^{+.006}_{-.005}$	$11.030^{\pm.003}$	$.3924^{+.0086}_{.0034}$	$11.0324^{+.0116}_{-.0124}$	$.3916^{+.0074}_{-.0056}$
US-4	$10.984^{\pm.003}$	$.5064^{+.0046}_{-.0024}$	$11.011^{\pm.001}$	$.4466^{+.0064}_{-.0076}$	$11.0446^{+.0084}_{-.0116}$	$3934^{+.0056}_{-.0064}$		
CF-8	$10.989^{\pm.009}$	$.5058^{+.0052}_{-.0038}$	$11.021^{+.007}_{-.008}$	$.4186^{+.0074}_{-.0066}$	$11.047^{+.010}_{-.018}$	$3946^{+.0110}_{-.0056}$		

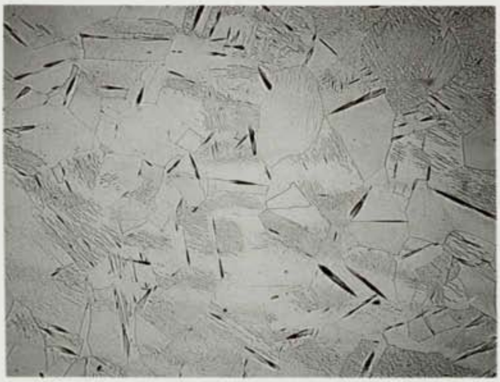
TABLE XXXV - FLOTURNED CYLINDERS ON HOLD

Forged A.I.S.I. 301 S.S. (Annealed)
Cylinder No. U.S. 1 (Heat 7-2067)
Magnification 100x

Forged A.I.S.I. 301 S.S. (Annealed)
Cylinder Number U.S. 2 (Heat 7-2067)
Magnification 100x

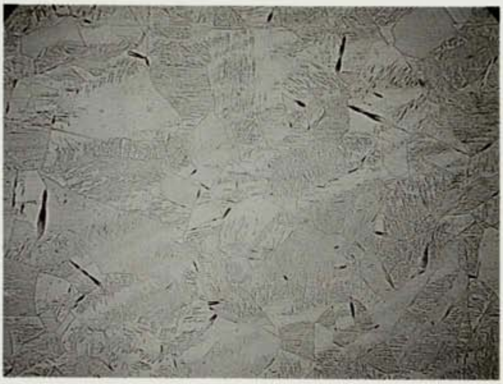
FIG. 46

Forged A.I.S.I. 301 S.S. (Annealed)
Cylinder Number U.S.5 Heat 7-2067)
Magnification 100x



Forged A.I.S.I. 301 S.S. (Annealed)
Cylinder No. CF 9 (Heat 7-2099)
Magnification 100x

FIG. 46



Forged A.I.S.I. 301 S.S. (Annealed)
Cylinder Number CF 10 (Heat 7-2099)
Magnification 100x

FIG 47

One macro photograph (5 separate photos) at 3.8x was taken showing the entire transition of material on cylinder US-5. This is shown in Figure 48 along with the estimated locations of each pass and anneal through the process.

After trimming the cylinders to length, the salvage was sectioned by Arde to note the effect of floturning passes on non-annealed grain structure. This information is presented in Figure 49. Tensile specimens wese also fabricated from this material, annealed, pickled, and passivated per Arde Specifications, and pulled to cryogenic failure. This was accomplished in order to study the effect of floturning on the cryogenic response of the material. It was determined that the stretch die as sized for the roll and weld vessels would be adequate for this material. The successive cold working appeared to stiffen the material somewhat over the as-forged state, but not sufficiently to warrant a die rework. An illustration of the specimens is presented in Figure 50. The resulting cryogenic true stress vs true strain curve is presented in Figure 51.

Head spinning operations at the Marison Company were commenced under Arde direction. A segmented sleeve was placed on each tube prior to processing, to insure no cylinder damage by the spinning machine rollers. The tubes were then heated in an open furnace. Furnace temperature was recorded at 2050°F in each case.

Unit CF-10 was placed in the furnace, and held for five minutes after the temperature regained its level of 2000°F. It was quickly crane-transferred to the machine, chucked in place, and a closure spun with a 3" diameter opening. (See Figures 52, 53 and 54 for spinning illustrations). The opposite end was heated in a similar manner and transferred for spinning.

MACROSECTION OF TOTAL WORK TRANSITION

Magnification 3.8x

FLOTURNED CYLINDER US-2

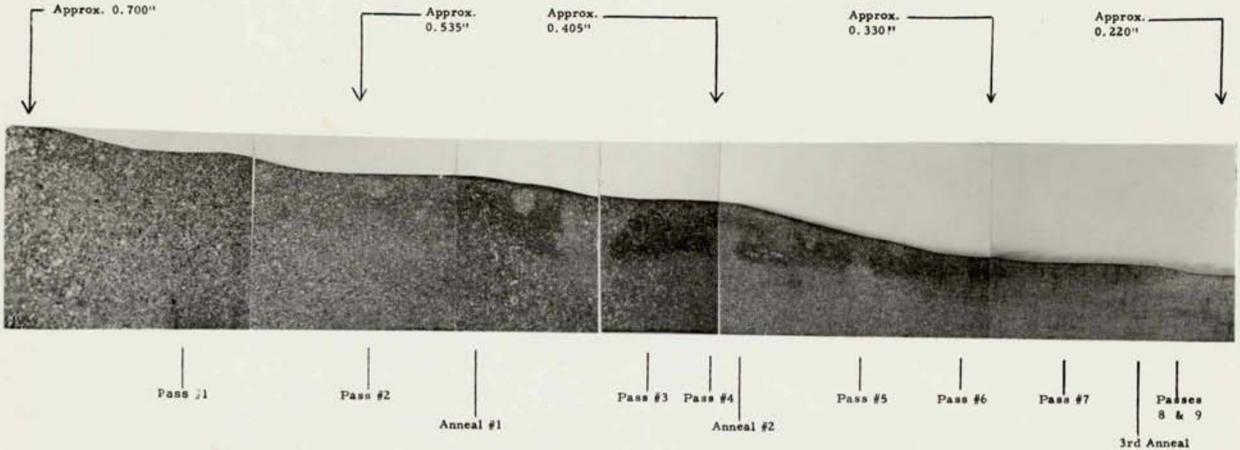
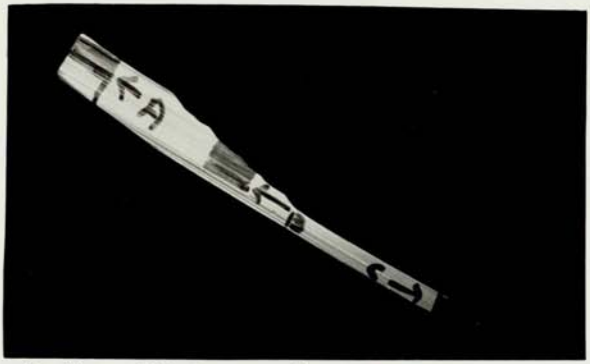


FIG 48



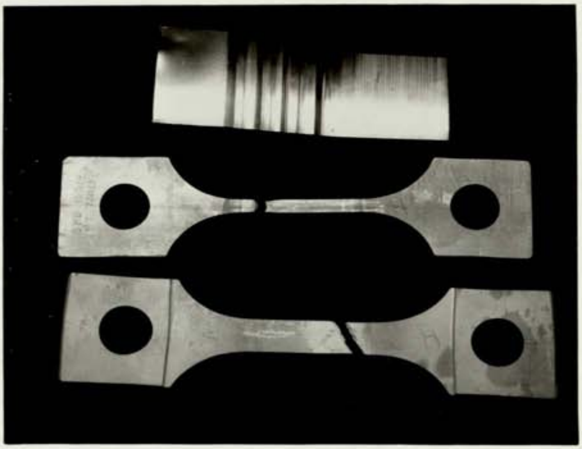
Section with Consecutive Flo-Turning Passes

Grain Structure at A
100 X
No Passes

Grain Structure at B
100 X
4 Passes

Grain Structure at C
100 X
6 Passes

FIG. 49



Heat 7-2067

As Flo-Turned Material with Specimens
Fabricated from Flo-Turned Material

FIG. 50

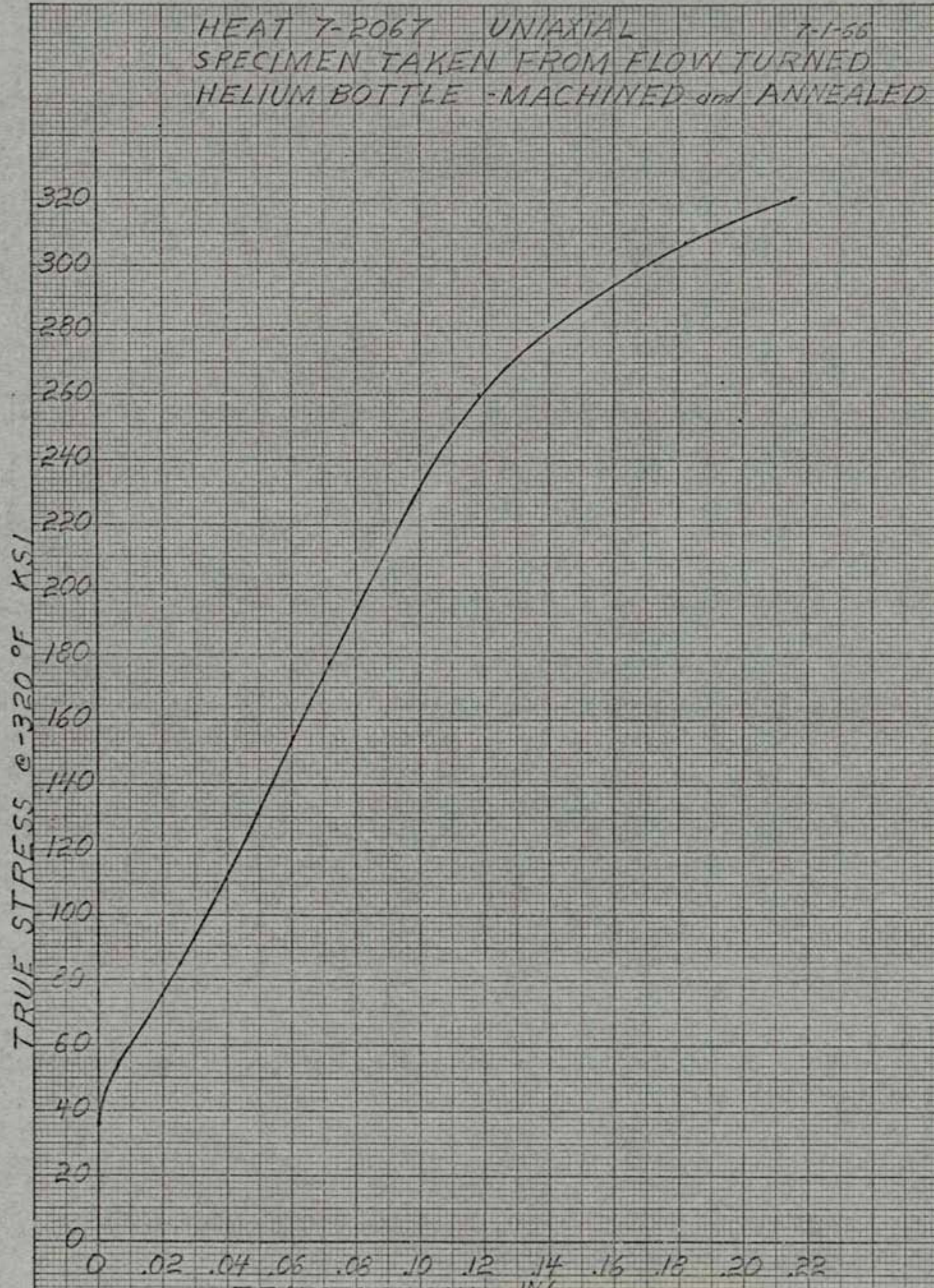

HEAT 7-2067 UNIAXIAL 7-1-56
SPECIMEN TAKEN FROM FLOW TURNED
HELIUM BOTTLE -MACHINED and ANNEALED
TRUE STRESS @-320 °F KSI
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
0 .02 .04 .06 .08 .10 .12 .14 .16 .18 .20 .22
TRUE STRAIN - IN/IN

FIGURE 51

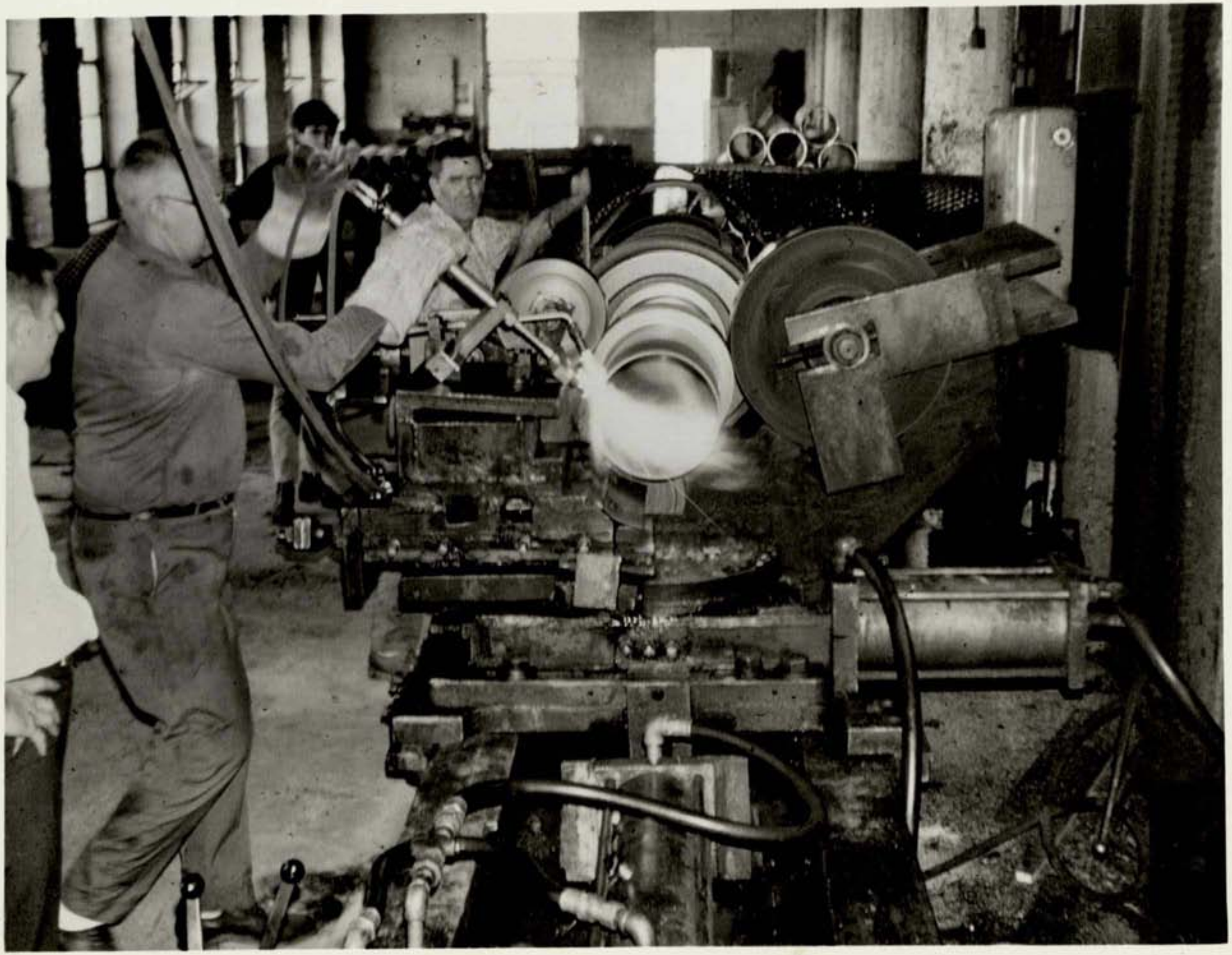
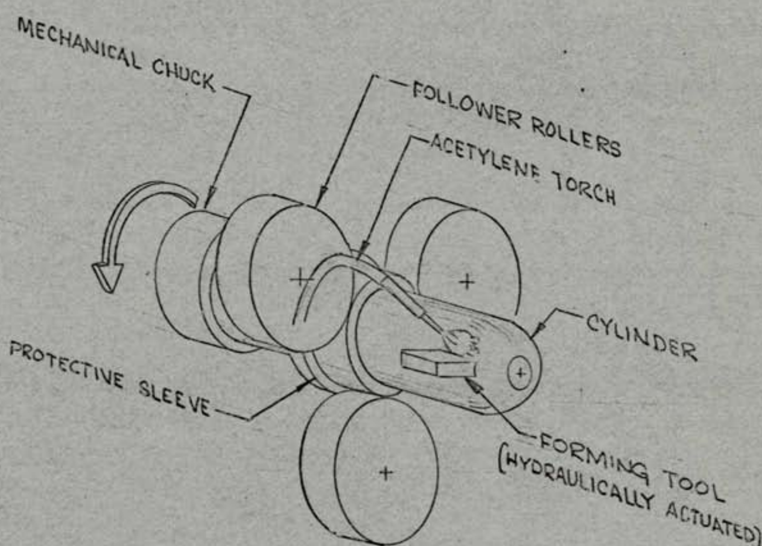


FIG. 52

FIG. 53



HOT SPINNING PROCESS SCHEMATIC

FIGURE 54

When the tube was closed to about a seven inch opening, it had cooled rapidly, and was returned to the furnace for reheating. It was held at temperature for five minutes again, and respun to a four inch opening. A large crack through the material and emanating from the opening appeared at the close of the spinning process. Thereafter, tubes were held at temperature for fifteen (15) minutes, and reheated after spinning process. Thereafter, tubes were held at temperature for fifteen (15) minutes, and reheated after spinning for stress relief.

In the spinning of cylinder US-5, it became obvious that there were serious problems with the chucking and alignment devices on the machine. The tube was expelled early in spinning and the head damaged. Adjustments were made, and the opposite end processed. The same situation developed, and the tube was set aside to have the damaged heads removed.

Two passes were attempted with an interpass heating cycle, to perform the head working prior to the tube slipping and eliminate cracking. However, slipping and the tendency for expulsion of the tube became more excessive, and US-2 was stopped after one head was formed. All internal parts in the chuck were replaced, and the machine realigned. US-2 was completed with two passes on the opposite end.

Cylinder CF-9 was processed with the head formed in two passes on one end, and a single pass on the opposite end.

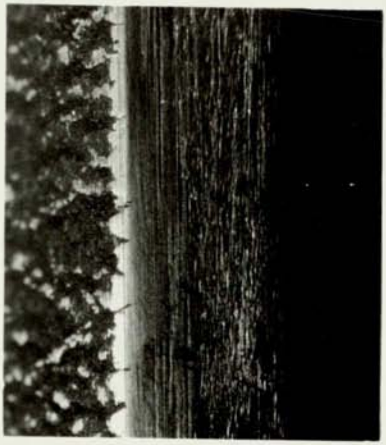
Cylinder US-5 was spun after the removal of the damaged heads. Slipping again became apparent, but the part was carried through processing without serious problems.

The cylinders with spun heads were returned to Arde-Portland, dimensionally inspected, and a machining program set up. Tracer templates were fabricated, and machining commended. The first operation was to bore a hole at the approximate boss size determined through X-ray and dye check techniques. Penetrant inspection revealed internal and external crack indications (see Figure 55). It soon became apparent that a stress relieving operation was required to keep the material from "walking" away from the tool. Inasmuch as insufficient material remain to take an internal machine cut on CF-9 due to distortion, the unit was placed on hold.

On the basis of experience with CF-9, units CF-10, US-2, and US-5 were tracer machined inside and outside on the heads to a .150 inch wall, removing all cracks. In order to remove all cracks, it was necessary to design and fabricate 6 1/2 inch diameter bosses for units US-5 and CF-10, and 5 1/2 inch diameter on US-2.

Unit US-5 was annealed and water quenched prior to welding the bosses in place. Distortion of the heads in the area of the boss opening occurred as a result of the quench, as may be seen in Figure 56. Therefore, units CF-10 and US-2 were air cooled after annealing. Although excessive scale occurred with air cooling, there was no distortion. The vessels were then grit blasted with silicon carbide to remove the scale from external and internal surfaces. A cold pickling operation followed, and the bosses were single pass welded in place.

INTEGRAL HEAD VESSEL



Photomacrograph

4 X

Photomicrograph

100 X

CRACKS ON INSIDE SURFACE
OF SPUN HEAD

S/N CF-9

NOT REPRODUCIBLE

FIG 55

INTEGRAL HEAD VESSEL

Distortion After Machining
and Annealing
(Typical of Both Ends)

FIG. 56

After X-ray and dye check inspection, the vessels were annealed with an argon purge and water quenched. See Figure 57. The bosses held the head in shape as desired, and no distortion occurred.

Vessel US-5 was salvaged by hand re-shaping of the distorted head in the boss attachment area. Bosses were welded in place, and processing completed as outlined above. All vessels were pickled and cryogenically stretched. Refer to Section V A, page 91, for a discussion of this operation, and Figure 58 for an illustration of a vessel being removed from the stretch pit.

Serial number CF-10 was cryogenically stretched at a pressure of 10,175 psi, which is equivalent to a forming stress of 272,300 psi (nominal). Dimensions before and after stretch are shown in Figure 59.

Units US-2 and US-5 were cryogenically stretched at somewhat lower pressures (9300 psi and 9350 psi respectively) because it became evident in processing that some repair grinding on the tube I.D.'s had reduced the wall thickness locally by as much as .033 inch. As a result, the vessels are slightly "cigar" shaped on the extremities because of insufficient pressure to force the material against the die all along the vessel length. Dimensions for these vessels may be found in Figures 60 and 61, and an illustration in Figure 62 of the vessels shipped to MSFC for evaluation.

Integral head vessel CF-10 was placed in the forming tank without the stretch die, and cryogenically burst at 10,300 psi. This represents a nominal hoop stress of 316,300 psi. The burst unit is shown in Figure 63.

The vessel was sectioned to provide a view of the integral head with the boss welded in place. This may be seen in Figure 64.

- 136 -

FIG. 57

NOT REPRODUCIBLE

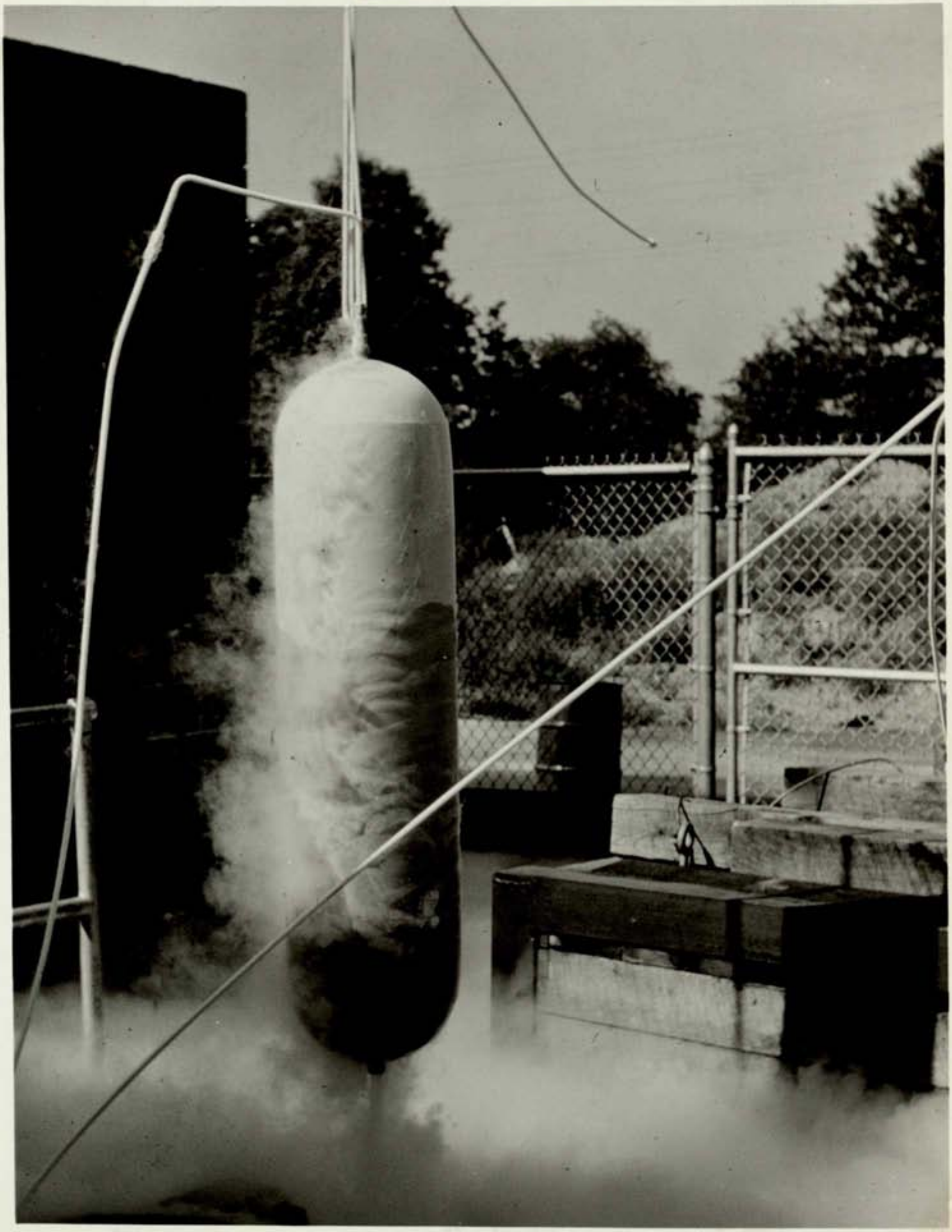
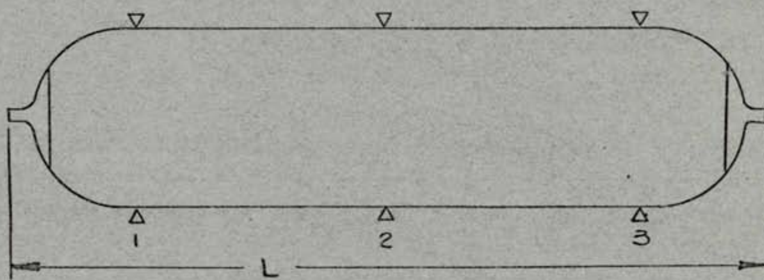


FIG. 58

D3435 INTEGRAL VESSEL S/N CF-10



PREFORM

DIA	1	11.550	L = 55.0
	2	11.495	
	3	11.505	

POSTFORM

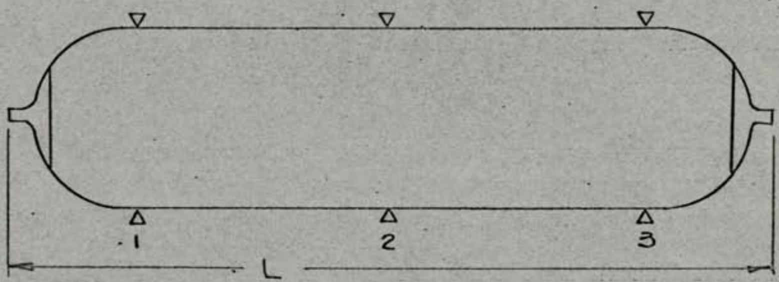
DIA	1	12.587	L = 55.38
	2	12.650	
	3	12.378	

STRETCH PRESSURE 10,175 PSI

(10.05% STRETCH)

FIGURE 59

D3435 INTEGRAL VESSEL S/N US-2



PREFORM

DIA 1	11.513	L = 56.38
2	11.506	
3	11.536	

POSTFORM

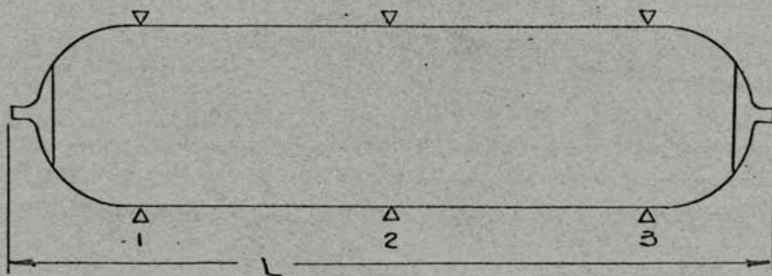
DIA 1	12.218	L = 57.12
2	12.644	WEIGHT = 112 LBS.
3	12.296	VOLUME: 3.28 CU.FT.

STRETCH PRESSURE · 9300 PSI

(9.9% STRETCH)

FIGURE 60

D3435 INTEGRAL VESSEL S/N US-5



PREFORM

DIA 1 11.525 L: 51.69

2 11.510

3 11.550

POSTFORM

DIA 1 12.350 L= 52.5

2 12.630 WEIGHT = 108 LBS.

3 12.325 VOLUME = 3.1 CU.FT.

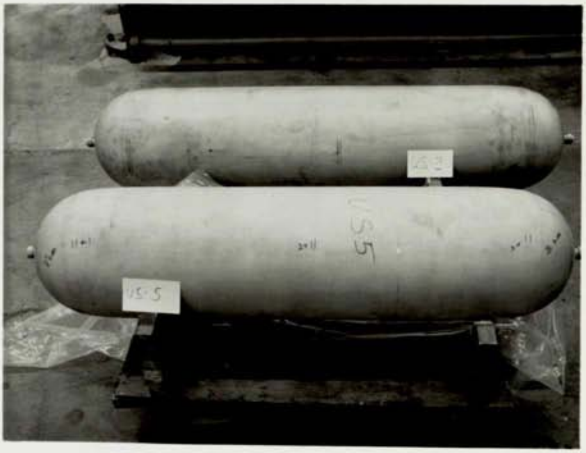
STRETCH PRESSURE 9350 PSI

(9.6% STRETCH)

FIGURE 61

INTEGRAL HEAD VESSEL

NOT REPRODUCIBLE



S/N's US-2 and US-5

After Cryogenic Stretching
at 9300 and 9350 psi Respectively

FIG. 62

INTEGRAL HEAD VESSEL

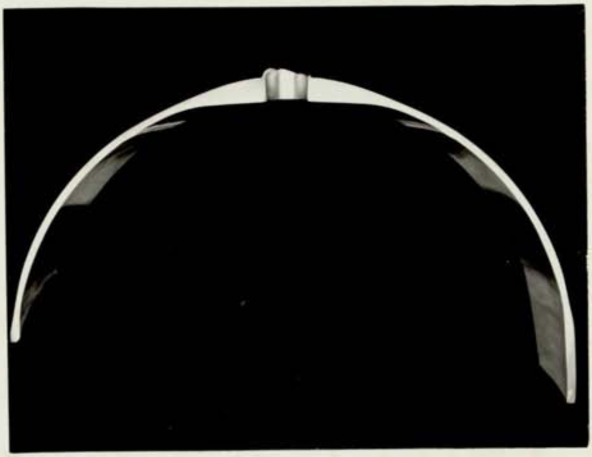
S/N CF-10

Cryogenic Burst at 10,300 psi

FIG. 63

INTEGRAL HEAD VESSEL

NOT REPRODUCIBLE



Section Cut from S/N CF-10

Hydroburst Unit

FIG. 64

VI CONCLUSIONS

The feasibility of fabrication of high pressure gas storage bottles for cryogenic service, by either of two approaches, was demonstrated in this program. Vessels were produced with 100% efficient welds, using standard Ardeform techniques, in one set of vessels. Through the development program, a second set of vessels was produced to essentially the same design. These vessels were seamless and had integral heads. The cryogenic burst level was within predictions for both designs.

Material properties data was provided for parent material as well as welded material, and process parameters were developed to provide for production with low reject rates.

A review of the results achieved in vessel fabrication and testing is provided in Tables XXXVI and XXXVII. In reviewing this data, it should be noted that although dimensional reproducibility was achieved in the welded vessels, it was not necessarily an objective of this program. The integral head vessels did not show this reproducibility for several reasons. For one thing, the seamless cylinders used were of slightly varying diameters, since the tubes produced in developing the process were used in final vessel fabrication. Additionally, lengths were not consistent because of the reforming of heads on tubes damaged in the head spinning operation. The spinning process did not lend itself to dimensional control with the existing tooling utilized in the forming of heads.

TABLE XXXVI

ROLL & WELD VESSEL - SUMMARY OF RESULTS

		S/N 1	S/N 3	S/N 4
Preform	Diameter at Center	11.390	11.403	11.376
	Average Wall Thickness	.216	.216	.216
	Forming Pressure	10,000 psi	10,000 psi	10,000 psi
Postform	Nominal Forming Stress	254.1 KSI	263.9 KSI	263.6 KSI
	Percent Stretch	9.94	9.7	9.96
	Diameter at Center	12.522	12.510	12.510
	Average Wall Thickness (Est.)	.195	.195	.195
	Weight in Pounds	92.4	92.1	91.7
	Volume in Cubic Feet	-	2.24	2.27
	Length/ Diameter	3.8	3.8	3.9
-320°F Burst	Burst Pressure	10,850 psi	-	-
	Nominal Hoop Strength at Burst	337 KSI	-	-
	Total Percent Stretch	11.43	-	-
	Diameter at Center	12.692	-	-
	Average Wall Thickness	.195	-	-
	Minimum Wall Thickness	.193	-	-
	Disposition	Stores	To MSFC	To MSFC

TABLE XXXVII

INTEGRAL HEAD VESSEL - SUMMARY OF RESULTS

		S/N CF-10	S/N US-2	S/N US-5
Preform	Diameter at Center	11.495	11.506	11.510
	Average Wall Thickness	.222	225	221
	Forming Pressure	10,175 psi	9300 psi	9350 psi
	Nominal Forming Stress	252.3 KSI	232.3 KSI	232 KSI
Postform	Percent Stretch	10.5	9.9	9.6
	Diameter at Center	12.650	12.644	12.630
	Average Wall Thickness (Est.)	.207	.205	.204
	Weight in Pounds	-	112	108
	Volume in Cubic Feet	-	3.28	3.1
	Length/Diameter	4.4	4.6	4.2
-320°F Burst	Burst Pressure	10,300 psi	-	-
	Nominal Hoop Strength at Burst	316.3 KSI	-	-
	Total Percent Stretch	13.5	-	-
	Diameter at Center	13.05	-	-
	Average Wall Thickness	.198	-	-
	Minimum Wall Thickness	.193	-	-
	Disposition	Stores	To MSFC	To MSFC

As shown in the previous sections, ultimate strength of Ardeformed material is dependent upon the prestress level. At the time of grit blasting the seamless cylinders, it was determined that some repair grinding, apparently to remove minor cracks or scratches, had been performed on the inside surfaces. As a result, the forming pressure was reduced in accordance with the reduced wall thickness. Because of the large variation in the effective wall thickness due to grinding (as much as .225 to .225 minus .033) it was a possibility that full calculated strength would not be developed throughout the cylindrical portion of the vessel. However, rather than revise the tolling or rebore the cylinders, fabrication was continued as indicated in the tables.

The materials evaluation program gave clear indication to the value of double vacuum melt heats in terms of cleanliness and minimum flaw-size. All objectives of the weld development program were met, as indicated by the results of both the vessel testing and mechanical testing programs. It was shown the full strength ground welds were produced with notch toughness and yield strength values comparable to those of the parent material.

VII - RECOMMENDATIONS

Problem areas encountered in the current program were with integral vessel fabrication, and can largely be segregated into two groups; those associated with floturning, and those associated with hot spinning.

<u>Flo-turning</u>:

(1) Inside diameter dimensional control, in the form of growth away from the mandrel, particularly in the center section. This growth resulted in non-uniform tubes, that did not achieve the design I.D. dimension.

(2) Cracking of parts during processing. Three out of ten tubes were lost in process due to cracking. Interpass annealing substantially reduced cracking.

<u>Hot Spinning</u>:

(1) Non-uniform head shapes and wall thicknesses from part to part.

(2) Non-uniform shape and wall thickness within a single part.

(3) Excessive inside and outside surface cracking.

(4) Distortion of basic tube.

Although some minor problems are still evident in the floturning process as applied to Ardeform materials, limited effort would undoubtedly alleviate most of these problems. Additional effort would certainly optimize the fabrication techniques. As

mentioned in Section V B, the last tubes processed (US-3, US-4, CF-8) show excellent dimensional control and would be available for future development work. The recommendations of both Parsons and Arde engineers are that future floturning of Ardeform material should be restricted to no more than 28% cold work in multiple pass without annealing, and single pass reductions should not exceed 14%. The annealing cycle must be more clearly controlled to preclude excessive carbide formations, which could result in minor or major cracking problems. With the exception of the above, practices on future floturning of Ardeform material should follow closely to the parameters established on Tube No. US-5.

More important advances, however, are required for the hot spinning process as used to form the integral head. The process itself would be difficult to optimize without first making equipment and tooling improvements. The machine used for spinning at the Marison Company had a chuck that allowed parts to escape during processing, the machine did not run true, causing whipping of the tube, and there were virtually no dimensional controls provided. Spinning was accomplished with one-point contact and no back-up, causing some bending and distortion of the basic tube. Furthermore, the entire operation is based on operator control, with no fixed positioning of the tool to insure reproducibility. Additionally, the nature of holding devices and material handling is such that there is virtually no temperature control. Improvement in tooling and temperature control would insure a low rejection rate. (It should be noted that Marison does provide better dimensional control on smaller diameter cylinders formed on other machines.)

Spherical vessels, seamless save for boss attachment, show potential with the processing developed in this program. It would also be advantageous to consider cold work with interpass annealing as an alternate to hot spinning for this application, in order to reduce the amount and extent of machining operations.

APPENDIX

AES NO.	251
DATE ISSUED 2/8/66	
REVISION	DATE REVISE

COLD PICKLING

APPROVALS	
PREPARED BY	ml
MET. ENG.	[illegible]
DESIGN ENG	[illegible]
QUALITY CONT	[illegible]
CHIEF ENG	[illegible]

ARDÉ, INC.
PARAMUS, N.J.

ENGINEERING SPECIFICATION
AES. 251

COLD PICKLING

1.0 SCOPE

1.1 This specification establishes procedures for the removal of acid soluble contaminants from the surfaces of aged 301 s.s. parts which have a geometry that permits thorough rinsing of all surfaces and will meet dimensional requirements after pickling.

2.0 DESCRIPTION

2.1 This specification is not to be confused with the hot pickling of annealed 301 s.s. parts. The principal difference between the cold pickling of aged material and the hot pickling of the annealed material lies in the fact that the aged material is martensitic.

3.0 APPLICABLE DOCUMENTS

3.1 The following documents form part of this specification to the extent specified herein.

Specifications:

Military

MIL-P-27401B	Nitrogen

ARDE

AES 360	Ageing
PCR-16	Pickling Solution Concentration Control

Commercial

A.C.S.	Acetone, Analytical
A.C.S.	Alcohol, Analytical Reagent
A.C.S.	Nitric Acid, Reagent
A.C.S.	Hydrofluoric Acid, Reagent

4.0 MATERIAL AND/OR SOLUTIONS

4.1 Demineralized Water - Water shall have an electrical conductivity of 0 to 200 micromhos.

4 2 Cold Tap Water - The cold tap water shall have a pH range of 6.0 to 8.0. If tanks are used for rinsing, the water changeover rate shall be such that the water in the tank shall not have a pH less than 6.0 three (3) minutes after introducing drained parts from the pickling tank

4.3 Pickling Solutions

4.3.1 Solution Preparation

4.3.1.1 Nitric-Hydrofluoric Acid Pickle - Solution shall be made up and maintained at the concentration specified below:

a) Nitric Acid 70 weight percent - 22 percent by volume ±3% total volume

b) Hydrofluoric 55 weight percent - 2 percent by volume ±.5% total volume

c) Tap Water - remaindor

d) The Cold Pickling solution shall be used at a temperature of 60° to 85°F.

4.3.2 Solution Maintenance

4.3.2.1 Nitric - Hydrofluoric Acid Pickle - Solution shall be maintained within the analysis limits specified in Para. 4.3.1.1 utilizing procedures indicated in PCR-16. When the dissolved iron build-up increases to 5%, the solution shall be discarded.

5.0 EQUIPMENT

5.1 Tanks

5.1.1 Acid Tanks - Steel construction lined with carbon brick. Tank must be equipped with heating and venting facilities.

5.1.2 Water Tanks - Steel construction coated with Teflon, polypropylene, or other suitable maskants - or austenitic stainless steel, uncoated.

5.2 Baskets, Racks and Wire Hangers - Coated or fabricated of Teflon, polypropylene or other suitable maskants for racking.

6.0 REQUIREMENTS

6.1 Cold Pickling shall be performed on parts which have been aged and quenched in accordance with AES 360.

6.2 Parts aged with Argon on their interior surfaces shall be cold pickled on their exterior surfaces only.

6.3 Parts aged without Argon protection shall be cold pickled on exterior and interior surfaces

6.4 Handling - All parts shall be handled with acid resistant rubber gloves during the pickling operation. Handling of parts during the rinsing and drying operation shall be performed in such a manner as to avoid contact of the metal surfaces with human skin. Operators shall wear rubber gloves during the rinsing and washing operations. During the drying operations, clean cotton, rubber or plastic gloves shall be used. Parts and vessels shall be placed only on equipment specified in Para. 5.0.

7.0 PROCEDURES

7.1 Argon Aged - Parts which have been aged with argon protection of their interior surfaces shall be plugged to prevent cold pickling solution from entering, then processed per Para. 7.3.

7.2 Aged in Air - Parts which have been aged without argon protection shall have all plugs removed to provide easy access to interior as well as exterior surfaces.

7.3 Cold Pickling Process - Aged parts shall be immersed in cold pickling solution for a maximum of 5 minutes, taking care that all surfaces to be pickled come in contact with the solution. The interior of vessels aged without argon protection must be cold pickled, care must be taken that total contact time between the pickling solution and any surface of the vessels does not exceed the five (5) minute limitation.

7.3 cont'd

NOTE: The time for filling and draining the cold pickling solution from vessels shall be included in the five (5) minute pickling time. Filling & draining time, therefore, shall not exceed a total of 2 minutes.

7.3.1 After cold pickling, the part shall be flushed with cold tap water on all surfaces. While still wet, all accessible surfaces shall be scrubbed with a wet tampico brush dipped in powdered pumice to remove and loosen any smut. Parts shall then be flushed with tap water to remove any loose smut. Rinse per Para. 7.4.

7.4 Cold Water Rinse - Rinse pickled surfaces of the parts in running tap water (Para. 4.2) at 60° to 85°F in a tank or by means of a spray for three (3) minutes. Vessels which have been subjected to argon protection of their interior surfaces shall remain plugged until all exterior surfaces are completely rinsed. Such vessels shall then be unplugged and their interior rinsed. The interior of all vessels shall be rinsed with the equivalent of at least two vessel volumes of cold tap water.

7.5 Drying - Drain on plastic coated wire rack until visible exterior surfaces are uniform in coloration and thoroughly dry. Vessels shall be drained with an open port or boss downward.

7.5.1 Closed Vessels - The interior of closed vessels shall be dried by flushing with 100 ml of ethyl alcohol per square foot of internal surface. The alcohol shall be drained from the vessel and disposed of.

The interior of the vessel shall be dried by purging with clean dry air per M.S.F.C. process 4.0.4 or nitrogen until all traces of alcohol disappear.

7.6 Grit Scrub - The scrubbing operation consists of introducing into the vessel some silicon carbide grit and shaking or rotating the vessel to remove light oxides and smut which are not removed from the vessel during the cold pickling operation.

7.6.1 Application - The grit scrubbing operation shall be performed on the interior of all aged pressure vessels, whether the vessel interior has been argon protected or not. Vessel interior shall be dried in accordance with para. 7.5 prior to the grit scrub.

7.6.2 Procedure - Approximately eight (8) fluid ounces of grit per square foot of interior surface shall be introduced into the dried vessel. The vessel shall be agitated, shaken or rotated so that the grit moves over the entire interior surface. The vessel shall be scrubbed in this manner until all scale, dirt or smut has been removed from the vessel interior. Vessels shall be scrubbed for a maximum of one hour. Vessels requiring more than one hour of scrubbing shall be held for M.R.B.

7.6.3 When the vessel interior is clean, the grit shall be poured or shaken from the vessel. Residual grit shall be completely removed from the vessel by flushing with tap water. Rinse per Para. 7.4.

7.7 Hot Water Wash - After cold water rinse per Para. 7.4 immerse the part in a bath of demineralized water (Para. 4.1) maintained at a temperature of 140-160°F for 3 to 15 minutes. The entire interior and exterior surfaces of all parts shall be in contact with the hot water.

7.7.1 Vessels shall be filled and drained at least twice. Repeat until all surfaces are free of mineral streak from the cold tap water previously used.

7.8 Dry - Dry per paragraph 7.5.

7.9 Packaging - Components shall be placed in a polyethlene bag immediately following drying process to prevent recontamination

7.10 Marking - Unless otherwise specified, all parts shall have complete traceability.

8.0 <u>QUALITY ASSURANCE</u>

8.1 The Inspection Department shall require adherence to the requirements and procedures outlined in this specification. These dispositions shall be recorded on applicable process sheets.

8.2 The Process Control Laboratory shall make daily checks of the specified solutions to insure operation within the specified analysis ranges. A copy of all reports of analysis shall be on file at the Quality Control Department.

AES NO.	253
DATE ISSUED	2/8/64
REVISION	DATE REVISED

CLEANING OF ARDEFORM COMPONENTS

APPROVALS	
PREPARED BY	mS
MET. ENG.	[illegible]
DESIGN ENG	[illegible]
QUALITY CONT	[illegible]
CHIEF ENG	[illegible]

ARDE, INC.
PARAMUS, N. J.

ENGINEERING SPECIFICATION
AES 253

SHEET 1 OF 5

[illegible]

1.0 SCOPE

1.1 This specification [illegible] the requirements of [illegible] for cleaning and inspecting the cleanliness level of all metallic surfaces to be [illegible] treated.

1.2 This specification is effective upon issue and shall be applicable when specified on Engineering Drawings.

1.3 This specification is applicable to all ARC facilities, to all ARC subcontractors and suppliers. Deviations may be granted by [illegible] Control Laboratory to subcontractors who are [illegible] to substitute their cleaning procedures if it is found to be equivalent or exceed the requirements of this specification.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein.

A.C.S.	–	Alcohol – Reagent Grade
MIL-P-2?4?1B	–	Nitrogen
[illegible]		[illegible]

3.0 [illegible]

[illegible]

3.1 [illegible]

3.2 Detergent: [illegible] Liquid – [illegible]

3.3 [illegible]

3.5 [illegible] Water – [illegible] shall have an electrical conductivity of 0 to [illegible].

4.0 EQUIPMENT

4.1 Tanks – Constructed from stainless steel or [illegible] material, equipped with heating facility, [illegible] with teflon or polypropylene or other suitable material.

4.2 Buckets, rack and wire hangers constructed or fabricated of teflon, polypropylene or other suitable material.

4.3 Gloves – Clean rubber or plastic during wet operation and clean cotton, rubber or plastic during dry operation – or equal.

5.0 REQUIREMENTS

5.1 Visible contamination – All surfaces of components shall be visually free of dirt, grease, oil or other foreign contamination.

5.2 Cleanliness Level – All surfaces shall be cleaned at a minimum to the following cleanliness levels:

5.2.1 Cold Water Rinse – There shall be no evidence of water breaks anywhere on surface.

5.2.2 Hot Water Rinse – There shall be no evidence of mineral streaks anywhere on surface.

6.0 PROCEDURE

6.1 Pre-cleaning – The pre-cleaning operation shall consist of cleaning the surfaces of components with fresh solvent.

6.1.1 Accessible Surfaces – All accessible surfaces of components shall be wiped with a clean sponge, disposable lint-free wiping cloth or paper saturated with solvent. A fresh

6.1.1 applicator shall be used for each square foot of surface wiped.

6.1.2 Interior Surface - The interior surface of closed pressure vessels shall be treated with a solvent rinse. 50 ml of fresh acetone per square foot of interior surface. Entire surface must come in contact with the solvent. Repeat the procedure with fresh solvent. Rinse the vessel with tap water at room temperature and drain. The volume of water used to rinse the vessel should be equivalent to at least 1/2 the vessel volume.

6.2 Detergent Wash - The parts shall be immersed for 2 to 15 minutes in the detergent solution maintained at a temperature of 140 - 160°F. All interior and exterior surfaces of the parts shall come into contact with the detergent solution. After the detergent soak, the exposed surfaces shall be vigorously scrubbed with a tampico brush. Immediately following the detergent wash, the vessel shall be rinsed as indicated in Paragraphs 5.3.2 and 5.3.3.

7.0 <u>RINSING</u>

7.1 Cold Water Rinse - Rinse the vessel with clean cold running tap water in a tank or by means of a spray. The interior of the vessel shall be rinsed at a minimum with the equivalent of the vessel volume of cold tap water. Cleanliness level per Paragraph 5.2.1.

7.2 Hot Water Wash - After the cold water rinse, immerse the vessel in a bath of demineralized water maintained at a temperature of 140° - 160°F for 3 to 15 minutes. The entire interior and exterior surface area of the vessel shall be in contact with the hot water. Vessels shall be filled and drained at least twice. Cleanliness level per Paragraph 5.2.2.

8.0 [illegible]

8.1 Exterior - Drain on racks until visible surfaces are uniform in coloration and thoroughly dry. Vessels shall be drained with an open port or boss downward.

8.2 Interior Surfaces - Flush with 100 ml of unused ethyl alcohol per square foot of internal surface. Purge with clean, dry, oil free air filtered per M.S.F.C. Process 404 or nitrogen until all traces of alcohol disappear.

9.0 Unit Packaging - Components shall be placed in a polyethlene bag immediately following the drying process to prevent recontamination.

9.1 Marking - Unless otherwise specified, all cleaned components shall have complete traceability.

10.0 Quality Assurance Provisions - The Quality Control Department shall require adherence to the confines of this specification by determining compliance with Paragraphs 3, 4, and 5 and by checking the following:

10.1 All parts, after cleaning shall be free from water breaks as evidenced by a smooth break free water film upon removal from final rinse.

10.2 The detergent bath shall be analyzed as often as required to insure operation within the required concentration range.

10.3 The detergent (if within the required PH factor) bath shall be discarded when it fails to produce surfaces free of water breaks; or when the sediment in the tank becomes excessive.

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PASSIVATING

APPROVALS	
PREPARED BY	md
MET. ENG.	[illegible]
DESIGN ENG	[illegible]
QUALITY CONT	[illegible]
CHIEF ENG	[illegible]

ARDÉ, INC.
PARAMUS, N.J.

ENGINEERING SPECIFICATION
AES 254

SHEET 1 OF

1.0 SCOPE

1.1 This specification covers the surface passivation of ARPS/ROUND parts.

1.2 This specification is effective upon issue and shall be applicable when specified on engineering drawings.

1.3 This specification is applicable to all ARPS facilities and to all ARPS subcontractors and suppliers. Deviations may be granted by Process Control Laboratory to subcontractors and suppliers to substitute their cleaning procedure if it is found to be equivalent or to exceed the requirements of this specification.

2.0 APPLICABLE DOCUMENTS

A.C.S.	Alcohol - Reagent Grade
MIL-P-27401B	Nitrogen
ARS 753	Cleaning of ARPS/ROUND Components
ARS 751	Cold Pickling
PCR 17	Passivating Solution Concentration Control

3.0 MATERIAL AND/OR SOLUTIONS

3.1 Passivating solution - Table I defines the composition of the two permissible solutions.

3.1.1 Solution Maintenance - The passivating solution shall be maintained within the analysis limits specified in Table I utilizing procedures indicated in PCR 17.

3.2 Cold Tap Water - ph range between 6.0 and 8.0.

3.3 Demineralized Water - Water shall have an electrical conductivity of 0 to 200 micromhos.

3.4 Alcohol

3.5 Nitric Acid - reagent grade

3.6 Sodium dichromate - reagent grade

3.7 Nitrogen

3.8 Polyethylene bags - 5 mil minimum thickness

4.0 [illegible]

4.1 [illegible] with [illegible] polypropylene.

4.2 Gloves – [illegible] gloves for passivating operation.

– clean rubber gloves for [illegible] and rinsing operation.

– clean cotton [illegible] or plastic gloves during dry operations.

4.3 Water Tanks – constructed [illegible] of [illegible] material [illegible] with [illegible] or other suitable [illegible].

4.4 Passivating Tanks – constructed from austenitic stainless steel or steel lined with carbon brick. [illegible] and temperature controls shall be provided when solution A is used (see Table I).

5.0 REQUIREMENTS

5.1 All surfaces must be cleaned in accordance with [illegible] 253 prior to passivating except when cold pickling has been performed in accordance with [illegible] 251.

5.2 Two alternate passivating solutions are used depending on whether the final part is intended for use with hydrogen peroxide or not. These solutions are described in Table I. Care shall be taken that all surfaces, interior and exterior, be in contact with the passivating solution.

5.3 Handling of all parts and vessels during the passivating operation shall be conducted with acid resistant rubber gloves. Handling of parts during the rinsing and drying operations shall be performed in such a manner as to avoid contact of [illegible] with human skin. Operators shall wear rubber gloves during the rinsing and [illegible] operations. During dry operations, clean cotton, rubber or plastic gloves shall be used. Parts and vessels shall be placed only on specially designed plastic [illegible] unless protected by the polyethylene wrapping.

6.0 [illegible]

6.1 Parts shall be immersed in the appropriate passivating solution for the period of time and at the temperature specified in Table I. After immersion, parts shall be removed from the solution and the contents of the vessel drained back into the [illegible].

6.2 After passivating, the parts shall immediately be rinsed in cold tap water at 60°F to 85°F in a tank or by means of a spray for three (3) minutes. If tank is used for rinsing, the water change-over rate shall be such that the water in the tank shall not have a pH less than 5.0 three (3) minutes after introducing drained parts from the passivating tank. The interior of all vessels shall be rinsed with the equivalent of at least two vessel volumes of the cold tap water.

6.3 After the cold water rinse, immerse the part in a bath of demineralized water maintained at a temperature of 140-170°F for 2 to 15 minutes. The entire inside and exterior surface area of all parts shall be in contact with the hot water. Vessels shall be filled and drained at least twice until all surfaces are free of mineral streaks from the cold water rinse.

6.4 Drain on plastic coated wire racks until visible exterior surfaces are uniform in coloration and thoroughly dry. Vessels shall be drained with an open port or ports downward.

6.4.1 Parts with ready access to inside and outside surfaces shall be stored in polyethylene bags when thoroughly dry.

6.4.2 The interior of closed pressure vessels shall be dried by flushing with 100 ml of absolute ethyl alcohol per square foot of internal surface. The alcohol shall be drained from the vessel and disposed of. The interior of the vessel shall be dried by purging with clean dry air or nitrogen until all traces of alcohol disappear. Vessels shall be stored in polyethylene bags after drying is complete.

7.0 MARKING

Unless otherwise specified, all parts shall be [illegible] traceability.

8.0 [illegible]

8.1 The Inspection Department shall monitor adherence to the requirements and procedures outlined in this specification. [illegible] shall be recorded on applicable process sheets.

8.2 The Process Control Laboratory shall make daily checks of the specified solutions to insure operation within the specified control ranges. A record of all [illegible] analysis shall be on file at the Quality Control Department.

TABLE I

PASSIVATION SOLUTIONS AND TREATMENTS

Solution Type	End Use of Part Being Passivated	Composition	Temperature	Time
A	All applications except hydrogen peroxide use	17% to 20% by volume of 70 weight percent Nitric Acid. 2 to 2½% by weight of sodium dichromate-dihydrate, water.	140 - 160°F	15-25 Min.
B	Hydrogen peroxide	70 weight percent Nitric Acid, reagent grade.	65 - 85°F	3 hours

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SOLUTION ANNEALING OF

ARDEFORM COMPONENTS AND ASSEMBLIES

APPROVALS		ARDÉ, INC. PARAMUS, N.J.
PREPARED BY	md	ENGINEERING SPECIFICATION AES 351
MET. ENG.	[illegible]	
DESIGN ENG	[illegible]	
QUALITY CONT	[illegible]	
CHIEF ENG	[illegible]	
		SHEET 1 OF 10

[illegible]

NOT REPRODUCIBLE

1.0 [illegible]

1.1 This specification covers the [illegible] of A[illegible] components and assemblies.

1.2 This specification is effective [illegible] and shall be applicable when specified [illegible] engineering drawings.

1.3 This specification is applicable to all A[illegible] facilities and to all A[illegible] subcontractors and suppliers.

2.0 APPLICABLE [illegible]

A[illegible] [illegible] = Cleaning of A[illegible] components

A[illegible] [illegible] = Thermal and Chemical Treatment [illegible] Processing

A[illegible] [illegible] = [illegible] of [illegible] and [illegible] Systems for [illegible] Processing

MIL-A-18455 [illegible] = Argon

3.0 MATERIALS

3.1 [illegible]

3.2 [illegible] MIL-A-[illegible]

4.0 [illegible]

4.1 Certified [illegible] per [illegible] Class 2

4.2 Quench tanks constructed of [illegible] steel or of [illegible] [illegible] completely protected with non-metallic paint or [illegible] with [illegible]

NOT REPRODUCIBLE

4.3 Spray simulator [illegible]

4.4 Heat treating fixtures [illegible] shall be made of [illegible] steel, [illegible]

4.5 Insulated [illegible] Argon [illegible] MIL-[illegible]

4.6 Back-fill conditions – stainless steel or other corrosion resistant material.

5.0 REQUIREMENTS

5.1 Furnace atmosphere. The furnace atmosphere shall be either air or Argon and shall be free of hydrocarbons, [illegible] sulfur [illegible] and hydrogen halides, [illegible] metals, [illegible]

5.1.1 Care should be taken that parts with shapes [illegible] into the furnace shall not have contaminated the furnace walls or floor with [illegible] materials such as plastic [illegible] with [illegible] grease.

NOT REPRODUCIBLE

[illegible]

[illegible] 1.5 gal of [illegible] each pound of [illegible]

[illegible]

5.3.2.3 [illegible] shall [illegible] the [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

5.4 [illegible]

[illegible]

5.4.1 [illegible]

Volume in Ft^3	Inlet & Outlet Port Nominal Diameter - in.
0 - .3	1/2
.3 - .78	[illegible]
.78 - 1.3	[illegible]
[illegible] - 3.1	[illegible]
3.1 - 4.9	5/8
4.9 - 7.0	3/4
[illegible] - 9.3	[illegible]
9.3 - [illegible]	1 [illegible]
over [illegible]	[illegible]

5.5 [illegible] shall be accompanied by certification that these conform [illegible]

5.6 Handling

5.6.1 Handling of all parts and vessels during and after the heat treating and quenching operation shall be done in such a manner as to avoid contact of the metal surfaces with human skin. Operators shall wear clean cotton or plastic gloves during the wet operations. During dry operations, clean cotton, rubber or plastic gloves may be used.

5.6.2 Quenched surfaces shall not be marked with grease pencil, crayons or any other marking device.

5.6.3 Parts and vessels shall not be placed indiscriminately on metal table tops or shop floors, but shall be placed only on specifically designated plastic [illegible] racks, unless protected by polyethylene wrapping.

6.0 PROCEDURE

6.1 Argon Purge - The interior of closed pressure vessels shall be filled with argon during the heating and quenching cycles, when required by the conditions as set forth in the [illegible] Section [illegible].

6.1.1 The vessel to be argon flushed shall be fitted with stainless steel tubing to permit the flow of argon through the interior. The exit line from the vessel [illegible]

will be placed inside the [illegible] shall be of [illegible] steel.

6.1.3 Initial purging shall be accomplished by a flow of Argon through the vessel and [illegible] in purging the vessel [illegible] the fixture.

The Argon flow shall be maintained at a rate and for a sufficiently long time to fill both the vessel and [illegible] containing with the equivalent of 7 volumes of gas.

Both [illegible] shall be held in a position during purging such that the Argon will fill the volume, forcing the initial air content of the [illegible] out through an upper [illegible] or opening.

After the initial purge, the flow of Argon into the vessel to be annealed, shall be regulated at 10 [illegible] or a rate equal to 7 volume changes, whichever is greater, with an exhaust opening of no less than specified in Table I. [illegible] the vessel placed into the annealing furnace. The Argon flow shall be maintained while the vessel is being annealed. The Argon flow rate shall also be maintained when the vessel is removed from the furnace and quenched in the quench bath or spray. The gas flow shall be maintained during quenching until the [illegible] of the vessel [illegible] the vessel [illegible] bath or [illegible].

6.2 [illegible] requirement of [illegible] shall be [illegible] accordance with the procedure outlined in 6.1.3 utilizing handling fixtures per 5.3.

6.2.1 [illegible]. The furnace temperature shall be raised to 1950°F ±25°F. The furnace [illegible] shall be [illegible] and a [illegible] temperature graph shall be obtained for a period of at least 2 minutes prior to charging parts into the furnace as well as [illegible] 2 minutes after removal from the furnace.

Said graph shall be marked with the serial numbers of all parts charged into the furnace and shall be transmitted to the Quality Control Department as verification of solution annealing temperature.

6.2.2 Charging Parts. Parts to be solution annealed shall be placed on suitable trays or racks meeting the requirements of Section 5.3 of this specification. When the furnace temperature has stabilized at 1950°F ±25°F for 5 minutes, the parts shall be charged into the furnace and positioned as follows:

6.2.2.1 Parts shall be positioned within the furnace hot zone.

6.2.2.2 Parts shall not be placed in direct contact with the furnace walls, nor should they be placed in contact with one another.

6.2.2.3 Parts shall be placed so that the distance between any two adjacent neighboring parts is equal to at least [illegible] the [illegible] of the [illegible] of the neighboring parts.

6.2.2.4 The positioning of parts within the furnace shall permit [illegible] [illegible].

6.2.3 [illegible]. After parts are charged into the furnace, they shall be maintained in the furnace for a period of time designated by the following formula:

[illegible]

Time (minutes) = 5 + 60 t, where t is the thickness of the heaviest portion of the part or portion of part that forms in direct contact with the vessel.

The time period in the formula shall apply after the furnace has reached 1950 ±25°F upon closing the furnace door.

6.2.4 Quenching. After parts have been maintained at temperature for the interval noted in the equation under 6.2.3, parts shall be rapidly removed from the furnace and immediately quenched in the quench tank or with a spray fixture.

6.2.4.1 Parts shall be quenched to 800°F from the solution annealing temperature within 10 seconds.

6.2.4.2 Parts shall remain in the quench tank or quench spray until their temperature has fallen just below 212°F; i.e. water on the surface does not hiss or spatter.

6.2.5 Draining. After parts are removed from the quench bath, they shall be placed on plastic coated wire racks to drain until all visible surfaces are dry. Closed pressure vessels shall be placed with an open port or boss downward for draining.

6.2.5.1 Parts which are to be pickled within 2 hours of quenching shall be moved after draining in a plastic coated wire tray or plastic tote box to the pickling area.

6.2.5.2 Parts and closed pressure vessels which are to be pickled later than two (2) hours after quenching shall be dried in accordance with PPS [illegible], Section 8.[illegible].

7.0 MARKING

Unless otherwise specified, annealed components and temperature control charts shall have complete traceability.

8.0 RECORDS

All temperature control charts shall be forwarded to [illegible] Quality Control Department.

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PENETRANT INSPECTION

APPROVALS		
PREPARED BY		[illegible]
MET. ENG.		[illegible]
DESIGN ENG		[illegible]
QUALITY CONT.		[illegible]
CHIEF ENG		[illegible]

ARDÉ, INC.
PARAMUS, N.J.

ENGINEERING SPECIFICATION
AES 451

PENETRANT INSPECTION

1.0 SCOPE

1.1 This specification covers the procedure for dye penetrant inspection (Type II - non-water washable) of ARDEFORM materials or components.

1.2 This specification is effective upon issue and shall be applicable when specified on engineering drawings.

2.0 APPLICABLE DOCUMENTS

AES 252 - Cleaning of ARDEFORM Components

3.0 MATERIALS

3.1 Penetrant - Magnaflux Type SKL - NF

3.2 Developer - Magnaflux Type SKD - NF

3.3 Cleaner - Magnaflux Type SKC - NF

4.0 EQUIPMENT

None

5.0 REQUIREMENTS

5.1 Surface Prepartion - Surfaces of welds or wrought metals may be inspected without surface preparation or conditioning except as required to remove scale or slag.

5.1.1 Welds - "As Welded" surfaces shall be considered suitable for liquid penetrant inspection provided excessive oxide and scale is removed.

5.1.2 Wrought Metals - Surfaces of wrought metals shall be conditioned only if necessary to remove excessive oxide and scale.

5.1.3 Finished Surfaces - Surfaces for which a specific finish is required shall be given this surface finish prior to the liquid penetrant inspection prescribed by the applicable specifications. Inspection at intermediate stages of fabrication, to reveal defects which may extend beyond the final dimensions, shall be permitted.

6.0 <u>PROCEDURE</u>

6.1 Pre-test Cleanliness - All materials being tested shall be cleaned by hot running water, by dipping in a solvent, or by swabbing with a clean lint-free cloth saturated with a volatile solvent. All surfaces shall be wiped dry with absorbent paper. Prior to penetrant inspection, the surface to be tested and any adjacent area shall be dry and free of any dirt, grease, lint, scale and other extraneous matter that would otherwise interfere with the test.

6.2 Temperature - The temperature of the penetrant and the part to be inspected shall be maintained between 50°F and 100°F. When inspection is necessary under conditions where the temperature of the penetrant and the inspection surface is outside the 50°F to 100°F range, the temperatures shall be adjusted to bring them within this range. Due to the flammable nature of the dye penetrant inspection materials, the use of an open flame for heating purposes is prohibited.

6.3 Application of Penetrant - Testing surface shall be uniformly coated by spraying, brushing, or immersion (parts must be penetrant covered at least 1" on both sides of weld to be inspection). Parts shall be completely wetted for a minimum of 15 minutes and a maximum of 20 minutes. If the time cycle is exceeded, the part shall be recleaned and the test re-run.

6.4 Removal of Excessive Penetrant - Surface shall be throughly wiped with clean, dry, absorbent paper or cloth. Remaining excess penetrant shall be removed by wiping the surface with a clean cloth or absorbent paper wiper, dampened with a qualified penetrant remover. Flushing any liquid on the surface after the application of the penetrant and prior to developing shall not be allowed. The drying of the test surfaces after removal of excess penetrant shall be done by normal evaporation, or by blotting with absorbent paper or clean lint-free cloth. Forced air circulation in excess of normal ventilation in the inspection area shall not be used. The time for surface drying after removal of excess penetrant, and prior to application of the developer, shall be limited to a maximum of ten minutes.

6.5 Application of Developer by Spraying - Wet developer will be used, developer shall be well agitated prior to using. The developer shall be uniformly applied in a thin coating to the test surfaces by spraying. If the geometry of the part inspected prevents the use of a spray, a brush or similar applicator may be used provided it results in a uniform thin coating of developer. Caution shall be used in avoiding pools of developer getting into cavities as this will cause heavy masking of the indications. Inspection shall be made in a minimum of seven minutes, and no later than thirty minutes after the developer has dried.

6.6 Removal of Excessive Developer - When inspection is completed, the developer shall be removed by means of the specified cleaner in conjunction with scratch-free cloths and paper towels.

6.7 Prior to any additional processing involving heat, parts should be cleaned per AES 253.

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SHIELDED TUNGSTEN ARC WELDING

APPROVALS		ARDE', INC. PARAMUS, N. J.
PREPARED BY	MS.	ENGINEERING SPECIFICATION AES 501
MET. ENG.	[illegible]	
DESIGN ENG	[illegible]	
QUALITY CONT	[illegible]	
CHIEF ENG	[illegible]	
		SHEET 1 OF 13

SHIELDED TUNGSTEN ARC WELDING

1.0 SCOPE

1.1 This specification covers the requirements for the fusion arc welding of stainless steel for the fabrication of ARDEFORMed components.

1.2 This specification is effective upon issue and shall be applicable when specified on engineering drawings.

1.3 This specification is applicable to all ARDE facilities and to all ARDE subcontractors and suppliers.

2.0 APPLICABLE DOCUMENTS

MIL-A-4144	Argon Gas, Welding
JAN STD-19	Joint Army-Navy Standard for Welding Symbols
MIL-STD-20	Welding Terms and Definition
MIL-T-5021	Qualification Tests for Welders
AES 252	Specification for 301 S.S. suitable for ARDEFORM
AES 253	Cleaning of ARDEFORM Components
AES 550	Inspection of Fusion Welded Joints
AES 351	Solution Annealing of ARDEFORM Components
AES 354	Passivating
Form M-100	Weld Defect and Disposition Report Form

3.0 MATERIALS

3.1 Polyethylene bags - 5 mil min. thickness

3.2 Acetone - A.C.S., Analytical Reagent

3.3 Argon - MIL-A-18455B

3.4 Helium - MIL-P-27407

4.0 EQUIPMENT

4.1 Brush - austenitic stainless steel wire brush.

4.2 Gloves - cotton.

4.3 Machine Welding Equipment - equipment shall have the following minimum characteristics:

a. Variable power supply capable of maintaining current within 5 percent of setting.

b. Arc voltage control capable of automatic control to within ±0.1 volt.

c. Automatic current decay and up slope.

d. Automatic wire feed capable of control to ±2 percent of setting.

e. Start and stop delay timers.

f. Carriage or boom spedd automatically controlled to ±2 percent of setting.

g. Automatic positioner capable of controlling work speed to ±2 percent of setting.

h. Automatic timers shall be reproducible within 2.5 percent of settings.

i. Helium and Argon supply system capable of delivering measured volumetric flow rates of dry cover and backup gas.

5.0 REQUIREMENTS

5.1 Classification of Welds - Welding shall be performed by the inert gas shielded arc (non-consumable) process using direct current, straight polarity. All welds shall be machine welds except for permissible manual welds as in Section 6.6.1.3.

5.2 Welding Terms and Symbols - Welding symbols and definitions of welding terms shall be in accordance with Standards JAN-STD-19 and MIL-STD-20.

5.3 Welding Operator Certification - Welding shall be performed only by welding operators who are currently certified in accordance with the requirements of specification MIL-T-5021.

5.4 Part Cleanliness - All parts to be welded shall be free from oil, grease, surface oxides and other foreign material.

5.5 Weld Joint Design - Square butt weld joints shall be used for material thickness up to 0.125 in. For thicknesses over 0.125 in., a V-groove weld may be used. The V-groove shall be kept to the minimum depth consistent with full penetration and uniformity of the weld bead.

5.6 Positioning of Parts for Welding - In positioning or aligning parts for welding, fixtures which restrain the joint during welding shall be avoided. Tack welds including 100 per cent tack welds are an acceptable means of aligning mating parts. The distance from weld joints to the closest line of contact between gas backup fixtures and parts to be joined shall be equal to 5 times the material thickness or 5/8 inch, whichever is less. The gas backup fixture should not restrain the weld joint. Tabs may be tacked to the ends of cylinders which are to be longitudinally welded, to provide for weld start and stop and for use as areas of hold down.

5.6.1 Joint Mismatch and Gap - Maximum allowable mismatch of assembled parts at the weld joint shall be 10 percent of the stock thickness of the thinnest member. Maximum allowable gap between assembled parts shall be 10 percent of the stock thickness of the thinnest member.

5.7 Filler Metal - The filler metal used shall be either AISI 308L or 301 of the chemistry specified in AES 252. Selection of this filler wire shall be in accordance with Table I.

TABLE I

FILLER METAL SELECTION

TYPE OF JOINT	FILLER METAL
a. Square butt	308L
b. Circumferential weld on a cylinder, V-groove, (mating components with thickness equal to or greater than material thickness at center of cylinder).	308L
c. Circumferential weld on a cylinder, V-groove, (mating components with thickness less than material thickness at center of cylinder by more than 15%).	301
d. Longitudinal weld on a cylinder, or any weld on a sphere, V-groove, (groove depth less than 30 percent of material thickness).	308L
e. Longitudinal weld on a cylinder, or any weld on a sphere, V-groove, (groove depth greater than 30 percent of material thickness).	301

5.8 Weld Wire Handling - Weld wire shall be stored in clean polyethylene bags and handled with clean cotton gloves. Wire may remain on machines if spool holders are completely enclosed and all wire is retracted into the holder when not in use. Auxiliary wire feed mechanism including spool holders should be inspected for cleanliness at the start of each shift and cleaned, if necessary, by wiping with lint free cloths saturated with acetone. However, as a minimum, a weekly cleaning schedule shall be adhered to for the wire feed equipment.

5.9 Tack Welds - Tack welds used for maintaining alignment of mating parts shall be limited to that width which will be consumed by the weld bead. Tack welds may be intermittent or continuous. In laying down continuous tack welds around a girth weld joint, tacks shall be made in an alternating sequence about the circumference. Succeeding tacks shall be placed so as to bisect the longest available arc length, and shall be angularly displaced as far from the preceding tack as possible. A continuous tack welded seam consists of short linear tacks which overlap each other, leaving zero spacing between tacks.

5.9.1 Fixturing during Tack Welding - Tack welding fixtures may be used to align the adjacent parts for tack welding. Tack welding fixtures should, however, be designed to minimize restraint as much as possible.

5.10 Inert Gas Protection - Argon, Helium or mixtures of both gases shall be used to protect the material during welding. Gases shall be free from contaminants such as hydrocarbons and shall have a dew point not to exceed -75F. Allowable oxygen levels in the Argon and Helium shall be 5ppm. Maximum specifications pertaining to gas purity shall apply at point of delivery to the work.

5.10.1 Backup Gas - Prior to welding, back side of joints shall be purged with inert gas in accordance with the following methods:

a. When gas backup rings are used, gas flow should be started a minimum of 5 minutes prior to the initiation of welding.

b. When an entire vessel is used as a backup gas container, the vessel shall be purged with 10 volume changes of gas prior to initiation of welding.

c. Gas flow should continue during welding and cooling at a rate sufficient to obtain welds having only superficial bronze discoloration. Care must be taken not to over pressurize the back side of welds which would result in weld blow out. Backup gas flow rates for any given gas exit area shall not exceed the rates shown on Graph I.

5.10.2 Cover Gas - Cover gas flow rates should be sufficient to produce welds having only discoloration which can easily be removed by light wire brushing.

5.11 Weld Quality - Weld quality shall meet acceptance standards set forth in AES 556.

5.12 Heat Treatment - All parts containing multi-pass and/or repair welds shall be heat treated in accordance with AES 351 prior to stretching.

5.13 General Handling and Cleanliness Requirements - All fixtures, positioner tables, back-up bars, etc., which may come into contact with parts to be welded shall be clean and free of grease, oil and dirt. Such metal surfaces shall not be constructed of aluminum or other reactive metals. Steel, stainless

steel and copper are acceptable. However, parts shall be passivated in accordance with AES 254 after contact with steel or copper surfaces. Surfaces of equipment which come into contact with parts to be welded shall be wiped clean with acetone at the start of each shift. Fixtures and tools which are removed from stores shall be cleaned with acetone prior to use in welding ARDEFORM parts.

Cleaned parts and weld wire shall be handled with cotton gloves - avoiding contact of human skin. Stainless steel wire brushes shall be cleaned in accordance with AES 253 and passivated and thoroughly rinsed in accordance with AES 254 every two weeks of use, and shall not be used on any surface other than stainless steel.

6.0 PROCEDURE

6.1 Weld Joint Preparation - Sheared edges shall be machined back a distance of .125 inches for material thicknesses up to .125 inch and 1.0T for material thicknesses over .125 inch, where T is the material thickness.

6.1.1 Joint preparation shall be by standard machining techniques. Where machine preparation is impractical, filing, or other manual processes are acceptable.

CAUTION: Grinding with a silicon carbide type wheel may impregnate the joint surface with foreign material.

6.2 Brushing - Prior to welding, parts shall be brushed along the entire joint with a clean austenitic stainless steel wire brush. The brushing shall cover a distance of one inch minimum from the joint. The brushing direction shall be parallel or tangential to the joint whichever is applicable.

6.3 Degreasing - After brushing, parts shall be cleaned and dried in accordance with PCR-4 and stored in clean polyethylene bags.

6.4 Welding Procedure - All welding shall be performed in accordance with developed weld schedules. The appropriate weld schedule shall be indicated on the process sheet.

6.4.1 Deviation of ±10% from the welding parameter indicated on the developed weld schedule is permissible if required as fine adjustments for the particular parts being welded. Parts for which adjustments beyond the allowed deviation is required, shall be held for evaluation by Engineering and Quality Control.

6.4.2 Start and stop of welds shall be made with automatic current up-slope and decay in accordance with the specified weld schedule. Tail-off of girth welds shall overlap the start of the weld and shall be located within the width of the starting weld. Operators shall try to center the tail-off within the width of the starting weld bead.

6.5 Tack Welding Procedure - Tack areas shall be adequately protected by cover and backup gas prior to, during, and after welding to assure minimum oxidation. Tacks should be lightly cleaned with a wire brush prior to final welding or overlap by additional tacks. A gas lens or equivalent diffusion apparatus shall be sued to assure adequate gas coverage of the tack weld. Tack welded parts shall be maintained in a clean dry condition and stored in polyethylene bags. No cleaning or other processing shall be performed on tack welded parts prior to final welding, except in Para. 6.2.

6.6 Weld Repairs - Weld repairs to eliminate weld defects are permitted only in accordance with the following:

a. Weld Defect and Disposition Report, ARDE Form M-100 must be completed and approved by Quality Control and Engineering prior to any weld repair.

b. The same area may not be weld repaired more than once.

c. Repair welded parts shall be annealed and quenched in accordance with AES 351.

d. Weld repairs shall meet acceptance standards set forth in AES 550.

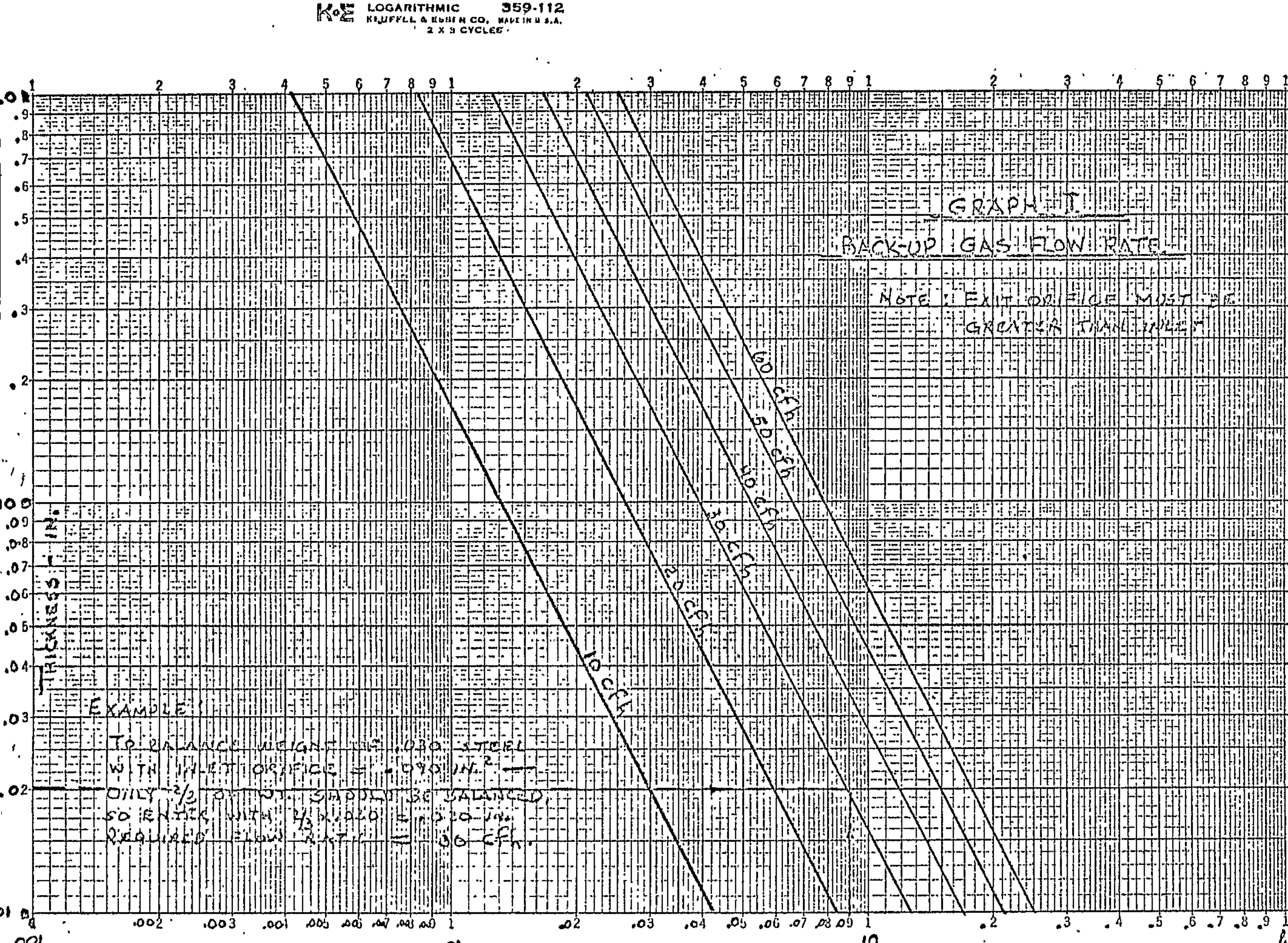
6.6.1 Weld Repair Procedures

6.6.1.1 Stock Removal - Weld defects such as voids, cracks and lack of fusion shall be completely removed prior to re-welding. Material removal should be by either conventional

machining methods or by local grinding with tungsten carbide burrs. At no time during the preparation for repair shall a silicon carbide or similar type grinding wheel be used unless precautions are taken to mechanically clean weld surface prior to welding. Stock removal at areas of incomplete penetration shall be minimal but sufficient to insure complete penetration of the joint upon re-welding. Material removal for weld repairs shall be confined to the fusion zone.

6.6.1.2 Cleaning - After required stock removal, areas should be wire brushed and cleaned by wiping with clean lint free cloths saturated with reagent grade acetone.

6.6.1.3 Repair Welding - Machine Welding is preferred, however, local manual welding is permitted where machine welding is impractical.



GRAPH I
BACK-UP GAS FLOW RATE
NOTE: EXIT ORIFICE MUST BE GREATER THAN INLET
60 cfh
50 cfh
40 cfh
30 cfh
20 cfh
10 cfh
EXAMPLE:
TO BALANCE WEIGHT OF .030 STEEL
WITH INLET ORIFICE = .090 IN.²
ONLY 2/3 WT. SHOULD BE BALANCED,
SO ENTER WITH 2/3 x .030 = .020 IN.
REQUIRED FLOW RATE = 30 cfh.
THICKNESS - IN.
INLET ORIFICE AREA - IN.²

AES NO.	550 A	
DATE ISSUED 2/8/66		
REVISION		DATE REVISED
A	REVISED TABLE II	6/20/66

INSPECTION OF FUSION WELDED JOINTS

APPROVALS		ARDÉ, INC. PARAMUS, N.J.
PREPARED BY		ENGINEERING SPECIFICATION AES 550 A
MET. ENG.		
DESIGN ENG		
QUALITY CONT		
CHIEF ENG		
		SHEET 1 OF 6

1.0 SCOPE

1.1 This specification covers the acceptability limits and/or requirements for visual, Dy Chek (Type II non-water washable dye penetrant), and radiographic inspection for fusion welded joints for ARDEFORM products.

1.2 This specification is effective upon issue and shall be applicable when specified on engineering drawings.

1.3 This specification is applicable to all ARDE facilities and to all ARDE subcontractors and suppliers. Deviations may be granted by the Process Control Laboratory to subcontractors and suppliers to substitute their inspection procedure if it is found to be equivalent or to exceed the requirements of this specification.

2.0 APPLICABLE DOCUMENTS

AES 501 Shielded Tungsten Arc Welding
AES 450 Inspection, Radiographic
AES 451 Penetrant Inspection

ARDE Form No. M-100 Weld Defect and Disposition Report

3.0 MATERIALS

NONE

4.0 EQUIPMENT

NONE

5.0 REQUIREMENTS

5.1 General Inspection - Inspection of welded joints shall be performed at the stages of the fabrication process specified below:

(a) After welding of details, subassemblies or final assemblies and before cryogenic stretching - visual, penetrant and X-ray inspection.

b) After cryogenic stretching and before hydrostatic testing - visual and penetrant inspection.

c) In multi-stretch operations between stretches - visual and penetrant inspection.

d) After hydrostatic testing - visual and penetrant inspection.

5.2 Radiographic inspection shall be performed in accordance with AES 430.

5.3 Penetrant inspection shall be performed in accordance with AES 431.

6.0 ACCEPTABILITY LIMITS

6.1 Visual Inspection - The acceptability limits for visual inspection of welded joints shall be as specified in Table I. Additional acceptability requirements are listed below:

a) The type of welding and size of weld bead shall be as specified by the weld symbols on the engineering drawing and AMCS Spec. AES 501, latest revision.

b) Weld beads shall be smooth and free from irregularities in accordance with good aircraft quality welding practice. The weld bead shall blend into adjacent parent metal in gradual smooth curves and should cover all tack welds.

c) Cracks, overlap, and lack of fusion of the weld as bead are not acceptable.

d. All porosities are not acceptable.

e) The penetration of the edge weld must be at least equal to the thickness of the thinner material welded, and the weld bead should slightly overlap the outer edges to insure sufficient melting down of the material to obtain the weld reinforcement when required.

f) The maximum height (crown) of a butt weld should not exceed one-third of the thickness of the parent material whenever the welding symbol does not designate either convex or flush contours.

g) Excessive penetration (underbead) of a butt weld should not exceed one-third of the thickness of the thinner parent material.

h) The size of the fillet welds designated on the welding symbols is the minimum size after any machining operation. The maximum size must not be greater than 1.5 times the values designated. Fillet weld size is the leg length of the largest isosceles right triangle which can be inscribed within the cross-sectional area of the weld.

6.2 RADIOGRAPHIC INSPECTION

The limits of acceptability shall be as specified in Table I for methods described in AES 450, latest revision.

6.3 PENETRANT INSPECTION

The limits of acceptability shall be as specified in Table I for Type II tap-water washable dye penetrant per AES 451, latest revision.

6.3.1 Blending of Defects - Areas which show dye check indications may be lightly blended with aluminum oxide abrasive paper or cloth no coarser than 400 grit. Metal removed as a result of blending shall not exceed 3% of the material thickness or a maximum of .005 in., whichever is least. Care should be taken in blending to avoid smearing the metal over cracks and thereby hiding the defect.

6.3.1.1 Acceptability of Blended Defects - Blended areas which show no dye check indications upon rechecking are acceptable. Blended areas which show a reduced intensity of the dye check indications upon rechecking shall still be subject to rejection.

7.0 WELD REPAIRS

When imperfections exceed the limits of Table I, repairs are permitted as outlined below:

a) Weld repairs will be made only on parts which have not yet been cryogenically stretched.

b) A "Weld Defect and Disposition Report", ARDE Form No. N-100 will be completed for any part that is rejected for not meeting the requirements of this specification. No weld repairs will be performed until this form is reviewed and approved by the appropriate authorities indicated on the form.

c) Material removal (e.g., grinding) for repairs at welds shall be confined to the fusion zone.

d) Each weld repair will be inspected in accordance with this specification.

e) All parts which have weld repairs shall be annealed before further processing.

f) The same area may not be weld repaired more than once.

TABLE I

ACCEPTANCE LIMITS FOR INSPECTION OF FUSION WELDED JOINTS

Type of Defect / Inspection Method	Visual	Radiographic	Dy Chek Penetrant
Cracks (weld & base material) including cavities or inclusions with a tail	U	U	U
Incomplete penetration or fusion	U	U	U
Porosity and voids:			
Max. size "D"	U	T/4 (up to .040 max.)	U
Max. Total length per linear inch	U	1 of Max. size or equiv. length. 3 Max. of any size	U
Min. distance between indications	U	5D	U
Metallic and non-metallic inclusions:			
Max. size "D"	N/A	T/4 (up to .040 max.)	N/A
Max. total length per linear inch		1 of max. size or equiv. length. 3 Max. of any size	
Min. distance between indications	U	5D	U
Undercutting:			
Max. depth and Max. length	U	U	U

Nomenclature:

U – Unacceptable

T – Thickness of thinnest base material

D – Diameter of largest dimension of actual defect